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THERMAL PROTECTION AND DIVER PERFORMANCE IN SPECIAL OPERATIONS FORCES COMBAT SWIMMERS (RESTING DIVER PHASE)

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NOTICES

TECHNICAL REVIEW AND APPROVAL

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The experiments reported herein were conducted according to the principles set forth in the current edition of the "Guide for the Care and Use of Laboratory Animals," Institute of Laboratory Animals Resources, National Research Council.

This technical report has been reviewed by the NMRI scientific and public affairs staff and is approved for publication. It is releasable to the National Technical Information Service where it will be available to the general public, including foreign nations.

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This study compared 4 different thermal protection garments/options for SEAL (Sea, Air, and Land) Delivery Vehicle (SDV) operators. Eighty man-dives were completed in a variety of water temperatures (36.5°F - 55°F) for up to an 8-hour duration with all of the divers remaining at rest. Each diver served as his own control by wearing each suit once in a given water temperature. The 4 suits tested, with the military unit/commercial company that they represent in parenthesis, were as follows:

1) Wet suit (SDV-2)
2) Viking dry suit (SDV-1)
3) British Royal Navy Special Boat Service (SBS) dry suit (SBS SDV unit)
4) Exotemp electric suit (Carleton Technologies, Inc., Tampa, FL)

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Major results of the study are as follows:

- The wet suit proved its great flexibility and reliability, but had limitations in very cold water -- an average dive duration of 2 h in 36.5°F water.
- Results favored the use of a dry suit in 36.5°F water, with the Viking dry suit providing moderate thermal protection in 36.5°F water, except for the hands and feet (where the thermal protection provided was poor).
- The dry suit as worn by the British SBS SDV unit provided the best thermal protection of a passive system, but sacrificed in-water manual dexterity and mobility.
- The electric suit significantly improved ($p<.05$) the dive duration of the Viking dry-suit system. The electric suit delivering 250 watts to the suit/diver extended the effective average duration of the Viking dry suit from 5 to 8 h in 36.5°F water. Seven out of 8 divers completed a full 8-h dive in 36.5°F water while wearing the electric suit. The electric suit also significantly improved final finger temperatures and post-dive tests of manual dexterity.

The electric suit, although not ideal, may be the best option currently available to significantly improve the thermal protection of an SDV operator. The shortcomings of the suit with recommendations for improvements are included in this report. However, with some minor modifications to the suit and adaptations of existing SDV batteries, this system could improve the thermal protection of SDV operators in the near future.

Therefore, the main recommendation of this report is to consider the Exotemp electric suit, with modifications, for further testing / authorized for navy use (ANU) evaluation.

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DEDICATION

As the legendary John Paul Jones once said, **"Men mean more than guns in the rating of a ship."** Therefore, while this study looked at various diving thermal garment suits, it was the men of this study and of the SEAL (Sea, Air, and Land) Delivery Vehicle (SDV) Teams that they represent who mean more than any piece of "gear" ever will. **Although procedures and equipment may change greatly over the years, the rugged, self-confident individual will remain the backbone of U.S. Special Operations and Naval Special Warfare.**

This study is dedicated to those men.

ACKNOWLEDGMENTS

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The opinions expressed in this paper are those of the author and do not reflect the official policy or position of the Department of the Navy, Department of Defense, or the U.S. Government.

The research reported employing human subjects was sanctioned by the Committee for the Protection of Human Subjects at the Naval Medical Research Institute and at the Naval Medical Research and Development Command. This research was also reviewed by the Defence Civil Institute of Environmental Medicine (DCIEM) and the Institute of Naval Medicine (INM) before Canadian and British participation, respectively, was approved. Additionally, approval was given by our Chief of Naval Operations office, the Canadian Director of Diving Safety, and the British Superintendent of Diving for participation of Canadian and British divers in this study.

BACKGROUND

Special Operations SEAL Delivery Vehicle (SDV) operators and combat swimmers are often required to carry out their missions in a cold-water environment. Successful completion of the mission and the safety of the diver are contingent upon adequate thermal protection. A variety of thermal protective garments are currently available to Naval Special Warfare (NSW) units, including layered wet-suit systems, variable volume dry suits, and other commercially available suits. Each of the wet and dry suits has a variety of configurations and a number of different hood, glove, and bootie combinations. There have been no previous studies that have examined all of these thermal protection options in a systematic manner in a variety of water temperatures, activity levels, and exposure times. In addition, there has been little attempt in the past to incorporate measurement of mission-related performance as an integral element of determining the adequacy of thermal protection.

OBJECTIVES

The first phase of this study, the “resting diver” phase, examined a number of thermal protection options for the “resting” diver (e.g., SDV operator) in a systematic manner in a variety of water temperatures.

Another phase of this study will focus on the "exercising" diver (e.g., the combat swimmer) and will be reported on separately.

The specific goals for the "resting diver" phase are as follows:

- To identify the particular thermal garments currently in use during SDV operations and alternative garments with potential for use in such operations.
- To test the relative efficacy and performance characteristics of the identified thermal protection garments in varying water temperatures. The adequacy of the thermal protection was in part determined by measurement of special operations forces (SOF) Mission-Related Performance (e.g., how accurately could the diver shoot after an 8-h dive in 36.5°F water after wearing suit "X" compared with suit "Y").
- To make recommendations concerning the relative effectiveness for each thermal garment.

METHODS

In order to design the study, SDV Team 1, SDV Team 2, and the British Royal Navy Special Boat Service (SBS) SDV unit were all contacted and site visits arranged. The Commanding Officers of both U.S. Navy SDV teams and numerous individual SDV operators (pilot/navigators) were interviewed to provide information on specific mission requirements, identify the thermal garments currently in use at these commands, describe advantages and disadvantages of currently used garments, and make recommendations for improved garment design and/or acquisition to better meet mission requirements.

The four thermal garment ensembles tested in this study reflect those garments currently used in SDV operations and one with potential for future use:

- A layered wet-suit system (as worn by SDV-2).

- The Viking dry suit with thinsulate undergarments (as worn by SDV-1).
- A neoprene dry suit with flectalon undergarments (as worn by the SBS).
- The actively-heated Exotemp electric suit manufactured by Carleton Technologies.

The Exotemp electric suit was selected because of its potential for use in an SDV application. This suit was chosen after an extensive market survey and because of its success in test dives done at the Defence Civil Institute of Environmental Medicine (DCIEM) (personal communication with Dr. David Eaton, DCIEM). Additionally, in order to make the best comparative study of the garments in this study, the electric suit was simply added to the Viking dry suit (as described above). This allowed a direct comparison between a passive and active system -- the Viking dry suit with and without the electric garment.

Photographs of all four of these thermal garment ensembles along with a much more detailed description of each are provided in Appendix A.

This study was conducted with 13 healthy male volunteers. The subjects represented a unique group of international military diving experience:

- 2 U.S. Navy SEALs from SDV-2 with recent SDV deployments as pilot/navigators wearing a layered wet-suit system.
- 2 British SBS swimmer-canoeists, with recent SDV deployments to Norway in the winter months as pilot/navigators wearing their own unique dry-suit ensemble.
- 1 Canadian Mine Clearance diver from DCIEM with electric-suit experience.

- 8 Naval Medical Research Institute (NMRI) divers with dry-suit diving experience.

All divers had no history of thermoregulatory problems, including hypothermia requiring medical intervention, frostbite, non-freezing cold injury (NFCI) (i.e., trenchfoot), chilblains, or heat exhaustion/stroke. Each provided informed consent to participate after having all methods, procedures, and risks explained to them.

The anthropometric characteristics of each subject, including height, weight, age, and percent body fat, are listed in Table 1.

TABLE 1. ANTHROPOMETRIC MEASUREMENTS
Thermal Garment Study (11 June 1996)

SUBJECT		Age	Height (cm)	Weight (kg)	% Fat	Triceps (mm)	Subscap (mm)	Chest (mm)	Axilla (mm)	Abd. (mm)	Supra-iliac (mm)	Thigh (mm)
1)	A	34	177.8	75.75	12.7	13	12	11	9	12	10	14
2)	B	33	175.3	74.5	19.8	19	20	20	16	22	21	20
3)	C	29	180.3	84.1	18.8	18	16	12	16	24	25	22
4)	D	27	172.7	69.85	9.2	6	13	5	8	8	15	7
5)	E	27	182.9	89.9	15.9	11	18	15	17	13	23	15
6)	F	26	172.7	69.4	12	9	13	6	8	14	19	14
7)	G	29	188	99.8	17.3	5	21	6	19	22	27	21
8)	H	33	182.2	85.73	19.6	16	15	16	22	16	25	26
9)	I	32	175.3	79.4	16.7	16	14	11	16	13	21	22
10)	J	42	186.7	91.6	23.2	14	22	19	30	30	27	16
11)	K	28	180.3	84.4	13.5	13	18	14	8	14	10	15
12)	L	41	175.3	75.3	9.8	9	10	6	9	8	7	6
13)	M	35	170.2	81.6	18.3	23	16	15	13	20	18	18

Subjects A - C were 3 NMRI divers who participated in research dives in all of the water temperatures, 36.5°F, 45°F, and 55°F (a total of 10 experimental dives/exposures each). Subjects D - H were the 5 divers from outside of NMRI (i.e., 2 SEALs, 2 British SBS SDV operators, and 1 Canadian Mine Clearance diver) who participated in research dives in the 36.5°F and 45°F water (a total of 6 experimental dives/exposures each). Subjects I - M were 5 NMRI divers who participated in research dives in the 55°F water only (a total of 4 experimental dives/exposures each).

All divers were instructed to abstain from alcohol, nicotine, caffeine, and strenuous exercise for 12 h prior to the dive. They were instructed to eat a hearty dinner and get a good night's sleep the day before the dive. All divers were provided a breakfast by the NMRI galley on the morning of the dive. The breakfast menus were patterned after *The Navy SEAL Nutrition Guide*[1] recommendations for energy and fluid intake for diving and immersion in cold water. Additionally, all divers drank 500 ml of water on the morning of the dive before entering the pool. Subjects did not drink or eat while in the pool.

On the morning of the dive, all divers underwent a fitness-to-dive evaluation by the duty diving medical officer and then attended the diving supervisor's brief.

The divers were instrumented for the measurement of rectal (internal) temperature by placing a thermistor 15 cm past the anal sphincter during all cold-water exposures. Rectal temperature was continuously measured throughout the dive as an index of internal temperature. Finger skin temperature was measured by the placement of a skin thermistor on the palmar aspect of the distal tip of the middle finger during all cold-water exposures. A three-lead electrocardiogram (EKG) was recorded to obtain heart rate and rhythm, which were monitored continuously during all experimental dives. Naked body weights were obtained prior to entering and immediately upon exiting the pool. Condom catheters were used to collect urine during the cold exposure dives.

The following is a list of the constant test conditions, the controlled variables, and the independent (measured) variables of the study.

Test Conditions

- Breathing gas – open circuit air
- Maximum depth of dive - 15 feet of seawater (fsw)
- Water composition - fresh
- Air temperature - room temperature (68-72 °F)
- Maximum duration of dive - 8 h

Controlled Variables

- Water temperatures - 36.5 °F (±1.5 °F), 45 °F (±0.5 °F), and 55 °F (±0.5 °F)

Note: 36.5°F, 45°F, and 55°F water temperatures were selected as representative of the "colder" areas of operation for SDVs.

- Duration of dives - 0.5 - 8 h

Note: 8 h continuous submersion was agreed to be a long-duration SDV mission (although some missions are longer).

- Workload - rest (the diver was allowed to move around the bottom of the pool but was not permitted to exercise in any manner)
- Diver's dress - one of 4 different thermal garment ensembles as previously described (see Appendix A for details).

Independent (measured) Variables

- rectal temperature
- finger skin temperature

- heart rate
- urine output
- pre- and post-dive body weights
- Systematic Investigation of Diver Behavior At Depth (SINDBAD), in-water performance measures (see Appendix B for details);

  SOF Performance Assessment Battery (PAB), performance tests done immediately after each dive (see Appendix B for details)
- subjective evaluations (verbal and written communications)

Each diver entered the water at a set temperature, with a given dress, and remained at rest. He then served as his own control on another day by entering the same water temperature and performing the same workload (rest), but wearing a different thermal garment. **The suits were worn in a random order**. A minimum time of 48 h was spent by each subject between exposures. From measurements of the independent variables, comparisons were made concerning the different thermal protective garments.

This study design favors a comparison of thermal garments. As each diver served as his own control, the differences due to individual variability are greatly reduced.

Once in the water, the divers watched underwater movies to help pass the time. Every 2 h they completed the in-water SINDBAD performance tests.

The cold water exposure/dive ended when any one of the following criteria were met:

- the diver's in-water time reached 8 h
- the diver desired to end the dive for any reason
- equipment malfunction
- the rectal temperature fell to 35 °C and remained there for 1 min -- 35 °C represents the upper limit of clinical mild hypothermia [2-4] (most sources list 33-35 °C as the limits of mild hypothermia) and the commonly accepted lower limit for cold exposure studies[5-8]
- any hand temperature fell below 8 °C and remained there for a period of 30 min or fell below 6 °C at any time -- the reason for this termination criteria was to prevent NFCI [9,10]
- any cardiac arrhythmia occurred or if a heart rate of less than 40 beats per minute (bpm) or greater than 160 bpm occurred -- the reason for this measure was to avoid cold-induced arrhythmia

Subjects exited the pool and took the SOF PAB.

Performance Measures

This research study focused on performance as a key measure of success of one garment over another. The two performance measurement systems were the SINDBAD (in-water performance measurement system) and the SOF PAB (dry/land-based performance tests of SOF mission-related tasks).

<u>SINDBAD</u>

The SINDBAD performance test battery was developed by the U.S. Navy in the late 1960s to provide a comprehensive method of testing human performance in

a hyperbaric and/or underwater environment.[11,12] It was successfully tested and evaluated at the Naval Experimental Diving Unit (NEDU) in 1974[13], and since then has been used in numerous diving studies.

Baseline tests were done on land with bare hands and then again in the water before any lengthy cold exposure with each of the thermal garments. Therefore, four baseline scores were obtained: 1) dry/land baseline, 2) wet-suit baseline, 3) Viking dry-suit baseline, and 4) SBS suit baseline. The electric suit had the same glove configuration as the Viking dry suit, except for a very thin spandex glove with wires woven only onto the dorsal aspect of the hand. It was determined that the Viking dry-suit baseline scores would apply to the electric suit as well.

The SINDBAD performance test battery consists of 3 manual dexterity tasks and 4 cognitive tests. They are explained below, in the order in which the diver performed the tests:

TEST	TESTS DIVER'S ABILITY
1) Key Insertion Test (B1)	- to manipulate a small object
2) Wrench and Cylinder Test (B2)	- to use a wrench
3) Stylus Test (B3)	- to rapidly tap a stylus or "pen"
4) Visual reaction time test (C1)	- to react quickly to a visual stimuli
5) Time Reproduction Test (D1)	- to estimate time
6) Visual Digit Span Test (I1)	- to recall a numerical sequence
7) Operations Test (K1)	- to solve mathematical problems

SOF PAB

The SOF PAB was developed by NMRI in response to a United States Special Operations Command (USSOCOM) tasking to standardize performance measures used in USSOCOM-sponsored research.[14,15] This battery of tests was designed to reflect

NSW mission-related performance. As such, this series of performance tests was used in this study to evaluate the relative efficacy of each thermal garment. If one thermal garment is significantly better than another, this benefit should be reflected in a reduced degradation of the ability to perform SOF-related tasks.

The SOF PAB consists of 5 physiological and 6 cognitive tests designed to test SOF mission-related tasks. Multiple baseline tests were done during the work-up phase of this study during times when the divers were well rested and not under thermally stressful conditions.

These tests were then performed by each diver immediately after each experimental dive. The divers exited the water and had their thermal garments removed sufficiently to expose their head, upper body, and hands. This took an average of 2-3 min. They then performed the first 2 tests of the SOF PAB (the hand-grip strength and weapon assembly tests). After that, the remainder of their thermal garment ensemble and all of their medical monitoring instrumentation was removed. This took an average of 5 - 7 min. Then they completed the physiological tests of the SOF PAB.

The cognitive tests were started approximately 20 - 30 min after ending the dive. This amount of time and the intervening physical activity (undressing, running steps, doing pull-ups, etc.) was not ideal, as it may have allowed the diver to rewarm. This delay was unavoidable. In other words, a post-dive ordering of the tests must be done, and inevitably some tests will be last.

The complete SOF PAB took approximately 30 - 45 min to complete (~ 15 min for the physiological tests and ~ 15 - 30 min for the cognitive tests).

The 5 physiological tests evaluate strength, endurance, fine and gross motor skills, eye-hand coordination, and vision. The tests are listed below in the order in which they were performed both before and after the experimental dives.

1) Maximal Hand-grip Force and Endurance Test
2) Disassembly and Reassembly of a Weapon (for time) Test
3) Maximal Repetitions during a Timed Step Test
4) Maximal Pull-ups Test
5) Marksmanship/Shooting Skills Test

The 6 cognitive tasks administered to the subjects in this study are listed below in the order in which they were presented on the computer during each session.

TEST	TESTS DIVER'S ABILITY
1) Matching-to-Sample	- to perform short-term memory task
2) Complex Reaction Time	- to quickly respond to a multiple-choice problem
3) Visual Vigilance	- to sustain his visual attention
4) Serial Addition - Subtraction	- to perform simple mathematical calculations
5) Logical Reasoning	- to reason
6) Repeated Acquisition	- to learn, or decode a new sequence

Photographs and a detailed discussion of the performance measures can be found in Appendix B.

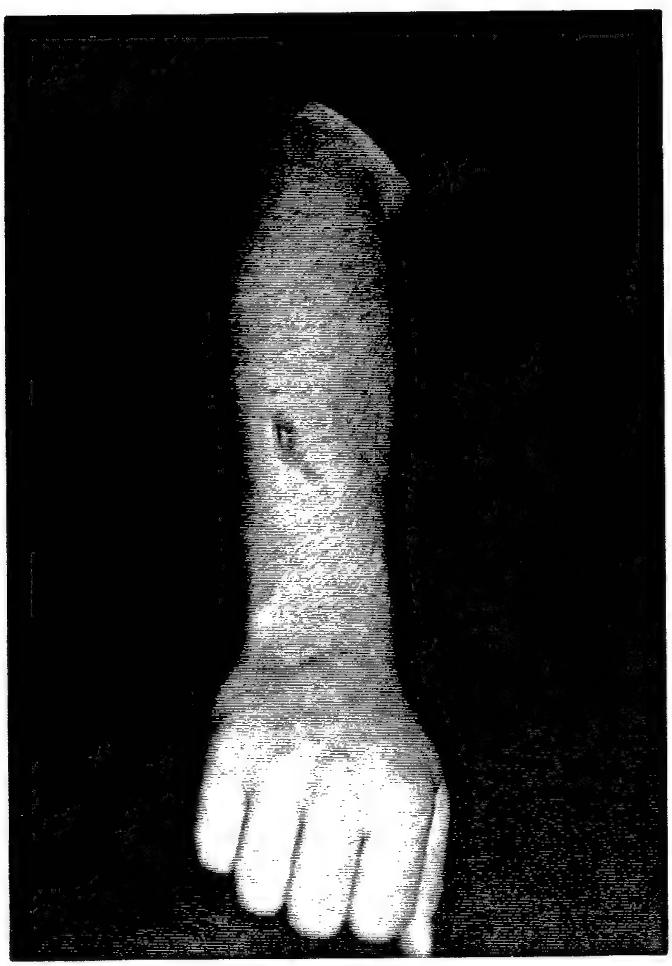
Statistical Analysis

The statistical method utilized to analyze the data was an analysis of variance with repeated measures. The suit type was considered the repeated measure. Differences between suits were evaluated for significance at the $p<.05$ level by the Newman-Keul's test.[16]

RESULTS

During the conduct of this study there was one injury. The electric suit caused one second degree burn to the forearm of a diver.

During a work-up/training dive in May 1996, a diver was wearing the electrically heated diving garment under a dry suit. Unbeknownst to the diver or the research team, the wire at the connection of the gloves was frayed. This exposed wire caused a small (1 cm x 2 cm) second degree burn to the diver's right forearm (see photos below). The diver felt the burn and immediately turned-off his electric suit. The diver was treated with standard wound care measures and the burn healed without complication.



This report will subdivide the "Results" section by the three different water temperatures tested. Within each water temperature tested, a comparison of thermal garments is made.

36.5 °F Water Dives

Eight divers participated and are reported on as subjects A - H. Each diver wore each of the suits once, for a total of 4 dives per man, or a total of 32 man-dives. A comparison of the thermal garments is summarized in Table 2.

TABLE 2. DIVES IN 36.5 ° F WATER – RESULTS				
	WET	VIKING	SBS	ELECTRIC
1) Average Dive Duration (minutes)	**120.5*1**	291.8	**390.1*2**	**470.0*3**
2) Average initial rectal temp. (°C)	37.4	37.4	37.1	37.2
3) Average lowest rectal temp. (°C)	36.7	36.5	36.5	36.5
4) Lowest individual rectal temp. (°C)	36.2	36.2	36.1	36.1
5) Average final rectal temp. (°C)	36.8	36.6	36.6	36.7
6) Average initial finger temp. (°C)	31.9	32.4	35.6	32.9
7) Average lowest finger temp. (°C)	10.9	10.5	13.3	16.5
8) Lowest individual finger temp. (°C)	7.5	8.0	11.3	10.3
9) Average final finger temp. (°C)	11.0	11.7	13.5	**18.4*4**
10) Average weight loss (kg)	1.2	1.4	**1.9*5**	**2.1*6**
11) Average urine output (ml)	985	1606	**1842*7**	**2107*8**

$p < .05$

[1] *The wet suit allowed <u>significantly less time</u> to be spent in the 36.5°F water than all of the other suits.*
[2] *The SBS suit allowed <u>significantly more time</u> to be spent in the 36.5°F water than the wet suit and Viking dry suit.*
[3] *The electric suit allowed <u>significantly more time</u> to be spent in the 36.5°F water than the wet suit and Viking dry suit.*
[4] *The electric suit's final finger temperature was <u>significantly warmer</u> than all of the other suits.*
[5] *Divers wearing the SBS suit had <u>significantly greater weight loss</u> than those wearing the wet suit.*
[6] *Divers wearing the electric suit had <u>significantly greater weight loss</u> than those wearing the wet suit and Viking dry suit.*
[7] *Divers wearing the SBS suit had <u>significantly greater total urine output</u> than those wearing the wet suit.*
[8] *Divers wearing the electric suit had <u>significantly greater total urine output</u> than those wearing the wet suit.*

Some key points to notice from Table 2:

Dive Duration

Some additional information concerning dive durations can be summarized as follows:

THERMAL GARMENT	AVERAGE DURATION	MINIMUM DURATION	MAXIMUM DURATION
Wet suit	2.0 h	32 min	3 h, 11 min
Viking suit	4.8 h	2 h, 25 min	8 h (by 2 divers)
SBS suit	6.5 h	3 h, 40 min	8 h (by 4 divers)
Electric suit	7.8 h	6 h, 40 min	8 h (by 7 divers)

Rectal Temperature

There was very little difference in rectal temperature among subjects in any of the suits. No diver reached a "hypothermic" (< 35 °C or 95 °F) rectal temperature and had to be removed from the water for safety and/or ethical concerns.

Finger Temperature

The electric suit's final finger temperature was significantly warmer than all of the other suits ($p<.05$).

Although a limited number of divers approached the dive termination criteria for finger temperatures (< 8 °C for 30 min or < 6 °C at any time), no diver actually reached a critical finger temperature and had to be removed from the water for safety and/or ethical concerns.

Weight Loss and Urine Output

In general, the rate of the "immersion diuresis" (increased rate of urine production due to water immersion) seen in this study was greatest in the first 1-2 h of the

dive. However, urine output continued throughout the dive. Therefore, the wet-suit diver whose average dive duration was 2 h had a urine output of ~1 liter, while the electric-suit diver whose average dive duration was ~8 h had a urine output of ~2 l. Weight loss was consistent with fluid losses.

Performance Tests

TABLE 3. MEAN RESULTS FROM THE FINAL IN-WATER PERFORMANCE TESTS IN 36.5 °F WATER

		WET	VIKING	SBS	ELECTRIC
SINDBAD, in-water Performance tests:	**- key insert (n) in 60 s**	5.8	3.1	**1.2*[1]**	3.0
	- wrench (n) in 120 s	4.0	4.7	**2.7*[1]**	4.3
	- tapping (n) in 30 s	67.6	102.3	64.2	80.7
	- reaction time (s)	0.30	0.30	0.30	0.32
	- time estimate (s)	-12.6	-15.1	-15.5	-12.5
	- digit span (n)	6.7	6.1	6.3	7.0
	- math (n) correct / (s)	19.6(2.2)	19.4(2.2)	18.7(2.1)	19.1(2.4)

** $p < .05$*

[1] The SBS suit demonstrated <u>significantly slower</u> performance of the key insertion test and wrench test compared with all of the other suits.

Recall that the SINDBAD tests were performed every 2 h of the cold-water dive. Table 3 represents the mean of the **final** SINDBAD test completed by the divers before exiting the pool.

TABLE 4. MEAN RESULTS FROM POST-DIVE SOF PAB PHYSIOLOGICAL TESTS AFTER DIVES IN 36.5 °F WATER		BASELINE	WET	VIKING	SBS	ELECTRIC
Physiology:	Grip (psi/s)	122/52	121/56	123/72	129/71	133/66
	Weapon assembly (s)	91.0	114.1	108.8	105.5	**88.6***[1]
	Steps (n) in 60 s	77.0	73.4	73.1	74.1	76.5
	Pull-ups (n)	15.1	14.1	14.7	15.1	15.5
	Marksmanship (hits / attempts)	16.1/35.9	14.8/34.7	13.6/34.7	13.8/33.5	14/38

**p* < .05
[1] *The electric suit allowed the weapon assembly task to be completed significantly faster than all of the other suits.*

TABLE 5. MEAN (SD) RESULTS FROM SOF PAB COGNITIVE TESTS AS PERCENT CORRECT (ACCURACY) AFTER DIVES IN 36.5 °F WATER	BASELINE	WET	VIKING	SBS	ELECTRIC
Matching-to-Sample					
Short Delay	0.76 (0.09)	0.71 (0.10)	0.73 (0.14)	0.72 (0.13)	0.64 (0.09)
Long Delay	0.70 (0.10)	0.64 (0.09)	0.67 (0.19)	0.64 (0.21)	0.58 (0.24)
Reaction Time	0.98 (0.01)	0.98 (0.02)	0.99 (0.01)	0.97 (0.005)	0.98 (0.02)
Addition-Subtraction	0.97 (0.02)	0.97 (0.03)	0.97 (0.02)	0.96 (0.02)	0.99 (0.01)
Logical Reasoning	0.88 (0.10)	0.82 (0.17)	0.85 (0.18)	0.84 (0.19)	**0.90 (0.15)***[1]
Vigilance					
Correct Detections	0.66 (0.23)	0.51 (0.34)	**0.38 (0.27)***[2]	0.65 (0.25)	0.45 (0.31)
Repeated Acquisition	0.74 (0.11)	0.74 (0.11)	0.74(0.14)	**0.84 (0.09)***[3]	0.77 (0.10)

**p* < .05
[1] *Accuracy of performance was significantly higher than that of all other suits.*
[2] *Accuracy of performance was significantly lower than baseline.*
[3] *Accuracy of performance was significantly greater than that of the wet suit.*

45 °F Water Dives

Eight divers participated and are reported on as subjects A - H. Each diver wore each of the suits once, for a total of 2 dives per man, or 16 total man-dives. A comparison of the 2 different thermal garments is summarized in Table 6.

TABLE 6. DIVES IN 45 °F WATER - RESULTS			
		WET SUIT	VIKING
1) Average Dive Duration	(minutes)	237.1	308.6
2) Average initial rectal temp.	(°C)	37.3	37.2
3) Average lowest rectal temp.	(°C)	36.5	36.4
4) Lowest individual rectal temp.	(°C)	35.8	35.9
5) Average final rectal temp.	(°C)	36.5	36.4
6) Average initial finger temp.	(°C)	33.9	31.5
7) Average lowest finger temp.	(°C)	11.5	11.0
8) Lowest individual finger temp.	(°C)	9.7	9.6
9) Average final finger temp.	(°C)	12.0	11.1
10) Average weight loss	(kg)	1.5	1.5
11) Average urine output	(ml)	1257	**1714*[1]**

**p* < .05

[1] *Divers wearing the Viking dry suit had <u>significantly greater total urine output</u> than those wearing the wet suit.*

Some key points to notice from Table 6:

Dive Duration

THERMAL GARMENT	AVERAGE DURATION	MINIMUM DURATION	MAXIMUM DURATION
Wet suit	3.9 h	2 h, 32 min	8 h (by 1 diver)
Viking suit	5.1 h	3 h, 30 min	8 h (by 2 divers)

Rectal Temperature

There was very little difference in any of the rectal temperature measurements between the suits. Also, it should be noted that in the "Lowest individual rectal temperature" measurement no diver reached a "hypothermic" (< 35 °C or 95 °F) rectal temperature and had to be removed from the water for safety and/or ethical concerns.

Finger Temperature

There was not a significant difference in finger temperatures between the wet suit and the dry suit. However, the hand protection was not good for either suit, as the average lowest and final finger temperatures were around 11°C. No diver reached a critical finger temperature and had to be removed from the water for safety and/or ethical concerns over finger temperature.

Weight Loss and Urine Output

Divers wearing the Viking dry suit had significantly greater urine output than those wearing the wet suit over the course of the entire dive ($p<.05$). The reason for this greater urine output may be that the average dive duration in the Viking dry suit was over one hour longer than the wet suit. As seen in the 36.5 °F water dives, increased dive duration leads to an increased urine output, which may lead to a decrement in performance.

Performance Tests

TABLE 7. MEAN RESULTS FROM THE FINAL IN-WATER PERFORMANCE TESTS IN 45°F WATER			
		WET SUIT	**VIKING**
SINDBAD, in-water performancs tests:	**- key insert (n) in 60 s**	3.5	2.3
	- wrench (n) in 120 s	5.0	5.3
	- tapping (n) in 30 s	67.2	91.7
	- reaction time (s)	0.31	0.30
	- time estimate (s)	-14.0	12.4
	- digit span (n)	6.7	6.6
	- math (n) correct / (s)	19.3(1.9)	19.5(2.0)

There were no statistically significant differences between the suits.

TABLE 8. MEAN RESULTS FROM POST-DIVE SOF PAB PHYSIOLOGICAL TESTS AFTER DIVES IN 45°F WATER				
		BASELINE	**WET SUIT**	**VIKING**
Physiology:	**Grip (psi/s)**	122/52	111/67	**124*[1]**/72
	Weapon Assembly (s)	**91.0*[2]**	117.5	110.8
	Steps (n) in 60 s	77.0	74.0	72.0
	Pull-ups (n)	15.13	14.3	14.8
	Marksmanship (hits/attempts)	16.1/35.9	14.1/32.3	13.8/33.5

** $p < .05$*

[1] The Viking dry suit allowed significantly greater maximum grip strength than the wet suit.

[2] There were significant decrements in the weapon assembly test post-dive with both the Viking dry suit and the wet suit compared with baseline.

TABLE 9. MEAN (SD) RESULTS FROM SOF PAB COGNITIVE TESTS AS PERCENT CORRECT (ACCURACY) AFTER DIVES IN 45°F WATER

	BASELINE	WET SUIT	VIKING
Matching-to-Sample			
Short Delay	0.76 (0.09)	0.73 (0.23)	0.64 (0.16)
Long Delay	0.71 (0.11)	0.67 (0.30)	0.61 (0.27)
Reaction Time	0.98 (0.01)	0.97 (0.04)	0.98 (0.01)
Addition-Subtraction	0.97 (0.02)	0.97 (0.02)	0.96 (0.02)
Logical Reasoning	0.88 (0.10)	0.89 (0.18)	0.83 (0.16)
Vigilance			
Correct Detections	**0.66 (0.23)** *[1]	0.42 (0.27)	0.35 (0.24)
Repeated Acquisition	0.74 (0.11)	0.81 (0.11)	0.80(0.11)

$p < .05$

[1] *Accuracy of performance was significantly lower than that of baseline, post-dive with both the wet suit and Viking dry suit.*

55 °F Water Dives

8 NMRI divers participated and are reported on as subjects A-C & I-M. Each diver wore each suit once, for a total of 4 dives per man, or 32 total man-dives. A comparison of the 4 different thermal garments is summarized in Table 10.

TABLE 10. DIVES IN 55 °F WATER - RESULTS					
		WET	VIKING	SBS	ELECTRIC
1) Average Dive Duration	**(minutes)**	270.7	356.5	**464.1*[1]**	**408.0*[2]**
2) Average initial rectal temp.	**(°C)**	37.5	37.4	37.3	37.4
3) Average lowest rectal temp.	**(°C)**	36.7	36.3	36.5	36.5
4) Lowest individual rectal temp.	**(°C)**	36.1	**35.0**	35.9	35.8
5) Average final rectal temp.	**(°C)**	36.7	36.4	36.6	36.6
6) Average initial finger temp.	**(°C)**	29.5	32.9	33.7	34.3
7) Average lowest finger temp.	**(°C)**	14.8	17.8	18.2	18.6
8) Lowest individual finger temp.	**(°C)**	13.8	13.8	15.9	16.8
9) Average final finger temp.	**(°C)**	15.2	18.1	18.9	**21.6*[3]**
10) Average weight loss	**(kg)**	1.9	2.1	2.4	2.3
11) Average urine output	**(ml)**	1733	2350	2431	2115

*$p < .05$
[1] *The SBS suit allowed significantly more time to be spent in the 55°F water than the wet suit.*
[2] *The electric suit allowed significantly more time to be spent in the 55°F water than the wet suit.*
[3] *The electric suit's final finger temperature was significantly warmer than with the wet suit.*

Some key points to notice from Table 10:

Dive Duration

THERMAL GARMENT	AVERAGE DURATION	MINIMUM DURATION	MAXIMUM DURATION
Wet suit	4.5 h	2 h, 1 min	8 h (by 1 diver)
Viking suit	5.9 h	1 h, 40 min	8 h (by 4 divers)
SBS suit	7.7 h	5 h, 23 min	8 h (by 7 divers)
Electric suit*	6.8 h	3 h, 58 min	8 h (by 5 divers)

** In this water temperature the electric suit was kept at only* ***122.5 watts*** *delivered to the suit/diver because warmer settings were reported by the divers as too warm.*

Rectal Temperature

In the 55°F water dives, Subject "J," wearing the Viking dry suit, did reach a rectal temperature of 35.0°C at the 7-h mark and had to be removed from the water for safety and ethical concerns.

Performance Tests

TABLE 11. MEAN RESULTS FROM THE FINAL IN-WATER PERFORMANCE TESTS IN 55 °F WATER					
		WET	VIKING	SBS	ELECTRIC
SINDBAD, in-water Performance tests:	**- key insert (n) in 60 s**	8.4	5.5	**2.7*[1]**	6.8
	- wrench (n) in 120 s	5.8	7.2	**3.6*[1]**	6.7
	- tapping (n) in 30 s	112.5	128.8	98.6	122.8
	- reaction time (s)	0.25	0.25	0.27	0.26
	- time estimate (s)	-6.3	-4.7	-5.6	-6.8
	- digit span (n)	6.4	7.1	7.0	6.5
	- math (n) correct / (s)	19.5(2.1)	18.4(2.1)	18.5(2.1)	18.7(2.0)

* *$p < .05$*

[1] *The SBS suit demonstrated <u>significantly slower</u> performance of the key insertion test and wrench test compared with all of the other suits.*

TABLE 12. MEAN RESULTS FROM POST-DIVE SOF PAB PHYSIOLOGICAL TESTS AFTER DIVES IN 55 °F WATER						
		BASELINE	**WET**	**VIKING**	**SBS**	**ELECTRIC**
Physiology:	**Grip (psi/s)**	**110/51**	106.5/73.7	113.1/76.1	122.1/71.6	115.2/72.3
	Weapon assembly (s)	**104.1**	**180.0*[1]**	124.8	136.0	116.8
	Steps (n) in 60 s	**71.1**	65.1	68.5	67.2	69.5
	Pull-ups (n)	**14.1**	12.4	13.6	13.7	13.3
	Marksmanship (hits / attempts)	**17.2/33.2**	13.4/35.2	12.7/38.0	13.8/32.6	11.6/38.2

*$p < .05$

[1] *The weapon assembly task was completed significantly slower than baseline with use of the wet suit.*

TABLE 13. MEAN (SD) RESULTS FROM SOF PAB COGNITIVE TESTS AS PERCENT CORRECT (ACCURACY) AFTER DIVES IN 55 °F WATER					
	BASELINE	**WET**	**VIKING**	**SBS**	**ELECTRIC**
Matching-to-Sample					
Short Delay	0.73 (0.06)	0.70 (0.16)	0.70 (0.28)	0.66 (0.24)	0.69 (0.16)
Long Delay	0.69 (0.06)	0.57 (0.13)	0.65 (0.21)	0.63 (0.16)	0.61 (0.18)
Reaction Time	0.98 (0.005)	0.97 (0.02)	0.95 (0.07)	0.97 (0.03)	0.98 (0.02)
Addition-Subtraction	0.98 (0.009)	0.98 (0.02)	0.94 (0.07)	0.94 (0.08)	0.96 (0.07)
Logical Reasoning	0.92 (0.03)	0.93 (0.08)	0.87 (0.11)	0.89 (0.15)	0.89 (0.17)
Vigilance					
Correct Detections	0.67 (0.30)	0.64 (0.27)	0.45 (0.34)	0.61 (0.35)	0.39 (0.29)
Repeated Acquisition	0.72 (0.11)	0.74 (0.07)	0.70 (0.11)	0.77 (0.07)	0.70 (0.07)

There were no statistically significant differences among the suits.

DISCUSSION

Dive Duration

Dive duration is a key measure of "suit success." It reflects an overall status of the diver and performance of a thermal garment. In this study, dive duration gave a good indication of how long a diver can reasonably expect to last before becoming uncomfortably cold/dehydrated/fatigued.

In summary, the electric suit and the SBS suit offered significantly greater dive durations than either the Viking dry suit or the wet suit.

None of the divers had to be pulled from the 36.5°F or 45°F water dives for a hypothermic rectal temperature or a dangerous finger temperature. Therefore all of the dives ended when the diver simply admitted that he was very uncomfortably cold or went for the full 8-h duration. Therefore, the measurement of dive duration gave a good indication of how long a diver can reasonably expect to last before becoming uncomfortably cold/dehydrated/fatigued in a given water temperature.

Based upon this study, however, the diver would probably not be "hypothermic" (have a rectal temperature <35°C) or have a finger temperature low enough to be at risk of NFCI (<8°C) at the point when he exited the water. Therefore, the dive durations might have been longer depending on the amount of discomfort the divers were able/willing to withstand. However, all divers who exited before the full 8 h exhibited one or more of the following: vigorous shivering, painfully cold extremities, or extreme fatigue/headache. It should be noted that the average of the two SEAL's dive durations was at or below the average of the other divers for all four thermal garments tested. **In**

other words, the SEAL divers did not stay in the water longer than the other divers.

Dive duration affected almost all of the other measures of "suit success," and this effect was not uniform for each suit. In other words, "lowest" and "final" temperature measures, urine output and weight-loss, and all of the performance measures were done much earlier for one suit (i.e., the wet suit) compared with another (i.e., the electric suit).

The dive durations in 55°F water might have been expected to be longer, based upon the results of the 36.5°F and 45°F water dives. In fact, the average dive durations for the wet suit and Viking dry suit in 45°F water were almost the same as seen in the 55°F water results. However, the dives in 55°F water were done by a mostly different group of divers, perhaps with a different level of cold tolerance. Additionally, perhaps cold stress is not the limiting factor when diving in this water temperature.

Still both the electric suit and the SBS dry suit allowed significantly more time to be spent in the 55°F water than the wet suit ($p<.01$).

Rectal Temperature

It should be noted that in the 55°F water dives, subject "J," wearing the Viking dry suit, did reach a rectal temperature of 35.0 °C at the 7-h mark and had to be removed from the water for safety and ethical concerns. Unlike all the other divers whose rectal temperature initially dropped and then hit a plateau around 36 °C, this diver's rectal temperature, on this day, continued to drop.

Upon being removed from the pool he reported feeling cold but "not that bad" -- he was noted to be shivering vigorously. All of his subsequent post-dive performance tests were well off his baseline scores.

In the 80 experimental man-dives conducted in this study, the only hypothermic rectal temperature noted was in a dry suit and in the warmest water temperature tested. **This emphasizes the great individual variability in terms of cold tolerance, and the great difficulty with trying to predict which cold exposures are potentially hazardous.** It also emphasizes the need for divers and diving supervisors to always be alert for the signs and symptoms of hypothermia and to take prompt action when recognized.

In the 36.5°F and 45°F water dives, no diver reached a hypothermic rectal temperature. Recall, however, that the longest dive in 36.5°F water in a wet suit was 3 hours 11 minutes. Therefore there might have been hypothermic (<35°C) rectal temperatures had the average wet-suit diver, for example, continued for 8 h in 36.5°F water.

Finger Temperature and Manual Dexterity

There was a significant difference in hand temperatures in this study as follows:

Average Final Finger Temperature after Dives in 36.5°F water

Wet Suit	Viking Suit	SBS Suit	Electric Suit
11.0°C	11.7°C	13.5°C	**18.4°C**

Through numerous previous studies, the following can be said about hand/finger temperatures and sensation/performance [17].

Hand/Finger Temp	Sensation / Performance
18°C	Hands feel mildly cold.
15°C	Hands feel uncomfortably/painfully cold.
10°C	Skin over hand is numb but pain persists because its origin is from constricted blood vessels.
8°C	If skin temps persist for a long period of time at this level there is a risk of NFCI (permanent cellular damage).
0°C	By definition frostbite (permanent cellular death) occurs when skin cells freeze.

In this study the electric suit kept hand temperatures well above the painfully cold/numb stage. The SBS suit kept hand temperatures above the numb stage but sacrificed in-water manual dexterity. Both the electric suit and the SBS suit kept hand temperatures warmer for a significantly longer period of time than either the wet suit or the Viking dry suit (in the "passive mode").

This improved hand temperature correlated well with the weapon disassembly/assembly task at the end of the dive. The average time to field strip and reassemble a weapon after dives in 36.5 °F water was as follows:

Wet Suit	Viking Suit	SBS Suit	Electric Suit	Baseline
114.1 s	108.8 s	105.5 s	**88.6 s**	91.3 s

The electric suit allowed the diver's hand temperatures to remain significantly warmer ($p<.05$) for a longer period of time than any other suit, and this translated into a significantly improved performance of a task of manual dexterity ($p<.05$) done immediately after the completion of his dive.

In the 45 °F water dives there was not a significant difference in finger temperatures between the wet suit and the dry suit. However, the hand protection was not good for either suit, as the average lowest and final finger temperatures were around 11 °C. This was almost identical to the average lowest and final finger temperatures seen in the wet suit and Viking dry suit in the 36.5 °F water dives, with the only difference being that it took approximately 1-2 h longer to reach these finger temperatures in the 45 °F water.

This translated into very similar findings in post-dive performance of manual dexterity (the weapons disassembly and reassembly task) as was seen in the 36.5 °F water dive results.

The average time to field strip and reassemble a weapon immediately post-dive in the 45 °F water dives with an average final finger temperature of **~11 °C** was as follows:

Wet Suit	Viking Suit	Baseline
117.5 s	**110.8 s**	91.3 s

Recall the average time to field strip and reassemble a weapon immediately post-dive in the 36.5 °F water dives, wearing the wet suit and Viking dry suit, with an average final finger temperature of **~11 °C** was as follows:

Wet Suit	Viking Suit	Baseline
114.1 s	**108.8 s**	91.3 s

This supports the argument that finger temperature is a very good predictor of manual dexterity abilities.

The difference in the average lowest and final finger temperatures among the wet-suit and the three other dry-suit ensembles in 55 °F is as follows:

Wet Suit	Viking Suit	SBS Suit	Electric Suit
~15.0 °C	≥18.0 °C	≥18.0 °C	≥18.0 °C

All of the dry-suit ensembles tested offered good thermal protection of the hands for dives in 55 °F water, as witnessed by their ability to keep finger temperatures ≥18.0 °C. The wet suit, however, allowed finger temperatures to drop into the uncomfortable/possibly painfully cold region of ~15.0 °C.

Weight and Fluid Loss

In the 36.5 °F water dives, the wet-suit diver whose average dive duration was 2 h had a urine output of ~1 l, while the electric-suit diver whose average dive duration was ~8 h had a urine output of ~2 l. Since fluid loss and dehydration have been shown to result in impaired physical performance(18,19), the degree to which dehydration affected performance must be considered in this study.

In short, the suits that allowed the diver to spend more time in the water were perhaps disproportionately negatively affected in terms of final diver performance because of the effect of increased dehydration. Weight loss was consistent with fluid losses.

In-water Performance

In terms of in-water performance, the most consistent finding was that **the glove ensemble of the SBS dry suit significantly impaired manual dexterity**. Additionally, although the wet suit offered very good initial manual dexterity, it degraded over time due to the cold to a point equivalent to that of a three-fingered dry-suit glove.

In terms of in-water cognitive performance, there was amazing consistency among all of the suits tested and at each water temperature tested. Divers, despite being cold and visibly shivering while taking their underwater cognitive tests, scored consistently near their baselines on all three cognitive tests. **In summary, in-water cognitive performance seemed unaffected by the cold.**

Post-dive Performance

In terms of post-dive performance of the SOF PAB **physiological tests**, the most consistent finding was that manual dexterity was degraded proportional to the drop in finger temperature -- the colder the finger temperature, the worse the performance on tests of manual dexterity (see the discussion above on "Finger Temperature and Manual Dexterity"). The remainder of the post-dive physiological tests of upper and lower body strength and marksmanship were consistently degraded from baseline, but not to a statistically significant level.

In terms of post-dive performance of the SOF PAB cognitive tests, there was very little degradation in performance. One explanation for the lack of significant degradation in post-dive cognitive performance may have been that these tests were (unavoidably) performed ~ 20 - 30 min after ending the dive. This time delay

may have allowed the diver to rewarm sufficiently to neutralize any difference that may have been seen in terms of cognitive ability.

Relative Effectiveness of the Thermal Garments

The following is a summary of the relative effectiveness of each of the garments tested and a discussion of the garments as they apply to SDV diving.

Wet Suit

A summary of the wet-suit results from this study:

- Least thermal protection: 36.5 $^{\circ}$F water -> avg Dive Duration = 2 h
  45 $^{\circ}$F water -> avg Dive Duration = 3.9 h
- Poor finger thermal protection: 36.5 $^{\circ}$F water -> avg final finger temp = 11°C
  45 $^{\circ}$F water -> avg final finger temp = 12°C
- The best initial/baseline tests of in-water manual dexterity, but the largest degradation of in-water manual dexterity over the shortest exposure times
- Worst post-dive measures of grip strength and manual dexterity

Points for discussion concerning the wet suit:

- SDV operators emphasized the great operational flexibility and reliability of the wet suit (over dry suits). **They stated that despite the obvious thermal benefits of a non-leaking dry suit, they would prefer the "colder" yet more reliable wet suit for all but the coldest water missions.**
- The SDV operators also emphasized the fact that many/most SDV diving operations are <u>not</u> in <40 $^{\circ}$F water. They expressed much interest in improving the operational

capability of the wet suit -- **specifically they recommended trying the electric suit under the wet suit .**

Viking Dry Suit

A summary of the Viking dry-suit results from this study:

- Moderate thermal protection: 36.5 °F water -> avg Dive Duration = 4.8 h
  45 °F water -> avg Dive Duration = 5.1 h
- Poor finger thermal protection: 36.5 °F water -> avg final finger temp = 11 °C
  45 °F water -> avg final finger temp = 11 °C
- Decrements noted in post-dive manual dexterity

Points for discussion concerning the Viking dry suit:

- The Viking dry suit's greatest weakness was the poor hand (and feet) thermal protection. The most common reason for ending a dive (by a diver wearing the Viking dry suit) was the complaint of cold hands and feet. **Therefore, hand thermal protection was the mission-limiting factor in this dry-suit system.**

SBS Dry Suit

A summary of the SBS dry-suit results from this study:

- Good thermal protection: 36.5 °F water -> avg Dive Duration 6.5 h
- Less than desirable hand / finger thermal protection but better than the Viking dry suit or the wet suit: 36.5 °F water -> average final finger temp = 13.5 °C
- The worst initial/baseline and final tests of in-water manual dexterity
- Decrements noted in post-dive manual dexterity

Points for discussion concerning the SBS dry suit:

- **The SBS dry suit proves the point that passive insulation alone (although bulky) protects the rectal temperature in long duration (8 h) dives in cold water (36.5 °F). However, passive insulation alone was not sufficient to maintain hand temperatures at a point desirable for SOF missions.**
- SBS SDV operators noted that although we had their exact dry-suit system, we had unknowingly altered their glove configuration. They typically wear the same ski glove for thermal protection but only wear a thin 5-fingered rubber glove for the outer waterproofing cover. This affords greater manual dexterity but decreased thermal protection for the hands than the 1/4" neoprene outer mitt that we used in this study. The SBS has experimented with electric gloves in order to improve the hand thermal protection of their dry-suit system, but has not arrived at a final version. The SDV operators were split in their opinion on whether the gloves as used in this study would enable the SDV operator to perform all of the necessary operational functions in a real SDV.
- SDV operators recommended that the suit be tested in the SDV trainer in Coronado to confirm that all of the routine and emergency procedures could be performed before any additional consideration is given to adopting the suit for possible U.S. fleet use.
- **Additionally, SDV operators felt the suit was simply not "swimmable" for any significant distance because of the suit's bulkiness.**

Electric Suit

A summary of the electric suit results from this study:

- **The electric suit caused one second degree burn to the forearm of a diver.**
- Best thermal protection: 36.5 °F water -> avg Dive Duration = 7.8 h
- Best finger thermal protection: 36.5 °F water -> avg final finger temp = 18.4 °C
- No decrements noted in post-dive manual dexterity (unlike the other suits tested)
- **Statistically significantly improved the dive duration of the Viking dry-suit system.** The electric suit delivering 250 watts to the suit/diver extended the effective duration of the Viking dry suit from 5 - 8 h in 36.5 °F water. It also significantly improved final finger temperatures and post-dive tests of manual dexterity (over the Viking dry suit without the electric garment).
- **Allowed 7 out of 8 divers to complete a full 8-h dive in 36.5 °F water.**

Points for discussion concerning the electric suit:

SDV operators generally felt the electric suit had promise and specifically recommended the following:

- **Consider the Exotemp electric suit, with minor modifications, for further testing / ANU evaluation.** This suit is not the ideal thermal garment, but it may be the best option currently available to significantly improve the thermal protection of an SDV operator. The shortcomings of the suit will be addressed in the following discussion, with recommendations for improvements. However, with some minor modifications to the suit and some adaptations of existing SDV batteries, this system could improve the thermal protection of SDV operators in the near future.

- **Test the electric suit under a wet suit.** SDV operators desired an active heating system that was flexible enough to improve diver thermal status in many applications. Therefore, if an SDV operation was to be conducted in, for example, $\geq$45 °F water, where wet suits would be a thermal protection option, then the electric suit may be able to significantly improve/enhance the diver's thermal protection, while still taking advantage of the wet suit's simplicity and reliability.
- **Improve or eliminate the connection of the gloves to the remainder of the electric suit.** This should greatly minimize the chance of a burn.
- **Improve the ability of the electric suit glove to pass through a dry-suit wrist seal**. In this study the gloves worn formed an air-tight seal to the dry suit, and therefore the latex wrist seal was not very important in terms of maintaining the water-tight integrity of the dry suit. It was noted, however, that if a glove leaked while wearing the electric suit, the water would pass into the body of the dry suit because of the strip of wires of the electric suit passing through the wrist seal. The SDV operators noted that when the dry suit is worn on SDV operations, frequently a wet-suit glove system is used for improved manual dexterity. As it currently exists, the electric gloves could not be successfully worn with a dry-suit system that utilized wet-suit gloves. **A smaller diameter wire would greatly improve the chances of the electric suit passing through a dry-suit wrist seal without leaking.**
- **One SDV battery "can" (30 battery cells) should be sufficient to provide 250 watts of heat to an electric suit for 6 divers for a long (~ 7 h) duration SDV**

mission in cold water. This can be calculated as follows:

The new SDV's battery arrangement is as follows:

- 4 battery "cans" per SDV
- 30 battery cells per "can"
- Each battery cell is 1.5 volts with 360 amp hours

In order to power a 5-volt electric suit (taking into account umbilical losses and voltage drop during discharge) with these SDV batteries, the following configuration might apply:

- Dedicate one battery "can" to heat six divers
- Divide the 30 cells in the "can" into 6, 5-cell batteries
- Wire the 5 cells in series (5 x 1.5 volts = 7.5 volts) and do this 6 times to utilize the entire battery "can"
- This creates 6, 5-cell batteries in parallel or 6 x 360 amp hours = 2160 amp hours
- 2160 amp hours / 50 amps = 43.2 h
- Assuming that the SDV battery "cans" are well insulated in their water-tight cans and have similar discharge characteristics, even in cold water, then this configuration should supply 6 divers with (5 volts x 50 amps) 250 watts of heat for (43.2 h/ 6) 7.2 h

- **Keep the electric suit at a low voltage (<6 volts) for an SDV application**. While higher voltage suits may be more efficient in their use of power in diving operations requiring a long umbilical, they should not be necessary for an SDV application that

will use a short (≤ 15 foot) umbilical. In other words, a higher voltage suit will not utilize less batteries / power in the SDV application. Therefore, the added safety of a lower voltage suit should be used for SDV diving.

Other recommendations concerning modifications to the electric suit include:

- **Keep the heat applied directly to the hands at or above the level that was used in this study.** In our study the average final finger temperature was 18 °C after 8 h in 36.5 °F water with the electric suit. This is very good thermal protection but recall that in our study the hand was in a dry glove. If SDV operators use this with a wet-suit glove (as is common practice), they will need at least as much heat as we supplied in this study and probably more.
- **Keep the feet heating as is.** In other words, keep the feet integral to the rest of the suit and keep the wires across the dorm (top) of the feet only. Wiring on the soles of the feet would be subject to an inordinate amount of wear and tear from walking and should not be included. But feet heating is mandatory, as feet easily get cold.
- For the sake of brevity, we will simply state that head heating is an area of potential benefit that could be investigated at a later date.
- The Association of Offshore Diving Contractors (AODC) Code of Practice for the Safe Use of Electricity Under Water[20] summarizes the acceptable practices for electrical diver heating. One of the requirements is that "the heating element in a suit ... should be completely enclosed in an earthed conducting screen." The Exotemp electric suit, as it currently exists, meets all of the other specifications for

the code of acceptable practices except this one. **Recommend Carleton Technologies, Inc. investigate using a metallized mylar material (just like the material used to make store-bought helium party balloons) to provide the grounded shield called for by the safety specifications**. Metallized mylar in this application has the following additional advantages:

- It will provide the grounded shield called for by the safety specifications
- No "waiver" will need to be granted to the electric suit (because it will then meet all of the safety specifications)
- It is inexpensive
- Although underwater radiant heat loss is only 1 - 2 % of total heat loss - it will provide a radiant heat barrier to the suit
- It will help distribute the heat of the electric suit across the body more evenly
- It will help protect against skin burns

According to the letter of the law, the wire should be "completely enclosed" in the grounded shield, but perhaps a simpler but equally effective and safe approach would be to "completely enclose the diver" from the wire in the metallized mylar. In other words, like a layered gortex-type jacket design, the metallized mylar layer could run continuously through the suit, underneath the wires. This would provide a grounded shield between the diver and the wires. An inner spandex layer could be added for ease of donning and diver comfort.

- **If whole body active heating is necessary for long-duration dives, then an even distribution of heat <u>must</u> be used.** The topic of skipping an area(s) of the body

with heating has occasionally been suggested. NEDU Report 3-90[21] addresses this issue. In this study the uneven heating of the S-TRON tube suit created dysaesthesia of overheating in all eight divers. A vagal response was noted after 30 - 45 min of exposure with severe nausea, malaise, salivation and bradycardia being reported by 2 of the 8 divers. These symptoms were both reversible and reproducible.

SUMMARY

Naval Medical Research Institute Report 96-47[22] reviewed over 300 manned experimental dives in cold water. These previous studies/dives represent a wide variety of thermal protective garments, water temperatures, activity levels, and exposure times. **In general, the findings of this study are consistent with the findings from these previous studies.**

Enclosure 1 is a VHS videotape summary of this dive study. It is approximately 25 min in duration and gives a good visual summary of the methods and results of the study.

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APPENDIX A

DETAILED DESCRIPTION OF THERMAL GARMENT ENSEMBLES

1.) Wet Suit

The wet suit was of a standard type manufactured for the SDV teams. The wet suit was constructed of foam neoprene and consisted of the following layers:

- 1mm "surf suit" worn against the skin
- 1/4" Farmer John
- 1/8" "cheater" vest with hood attached
- 1/4" jacket, worn with a 1/4" hood
- 1/8" five-finger glove
- 1/4" outer "gauntlet" mitten

WET SUIT LAYERS

Note: The diver's first layer consisted of a 1mm "surf suit" worn against the skin. Also notice the diver holding the urine collection bag, EKG block and temperature sensor wires.

WET SUIT LAYERS

Note: The diver's second layer consisted of a 1/4" Farmer John and 1/8" "cheater" vest with hood attached.

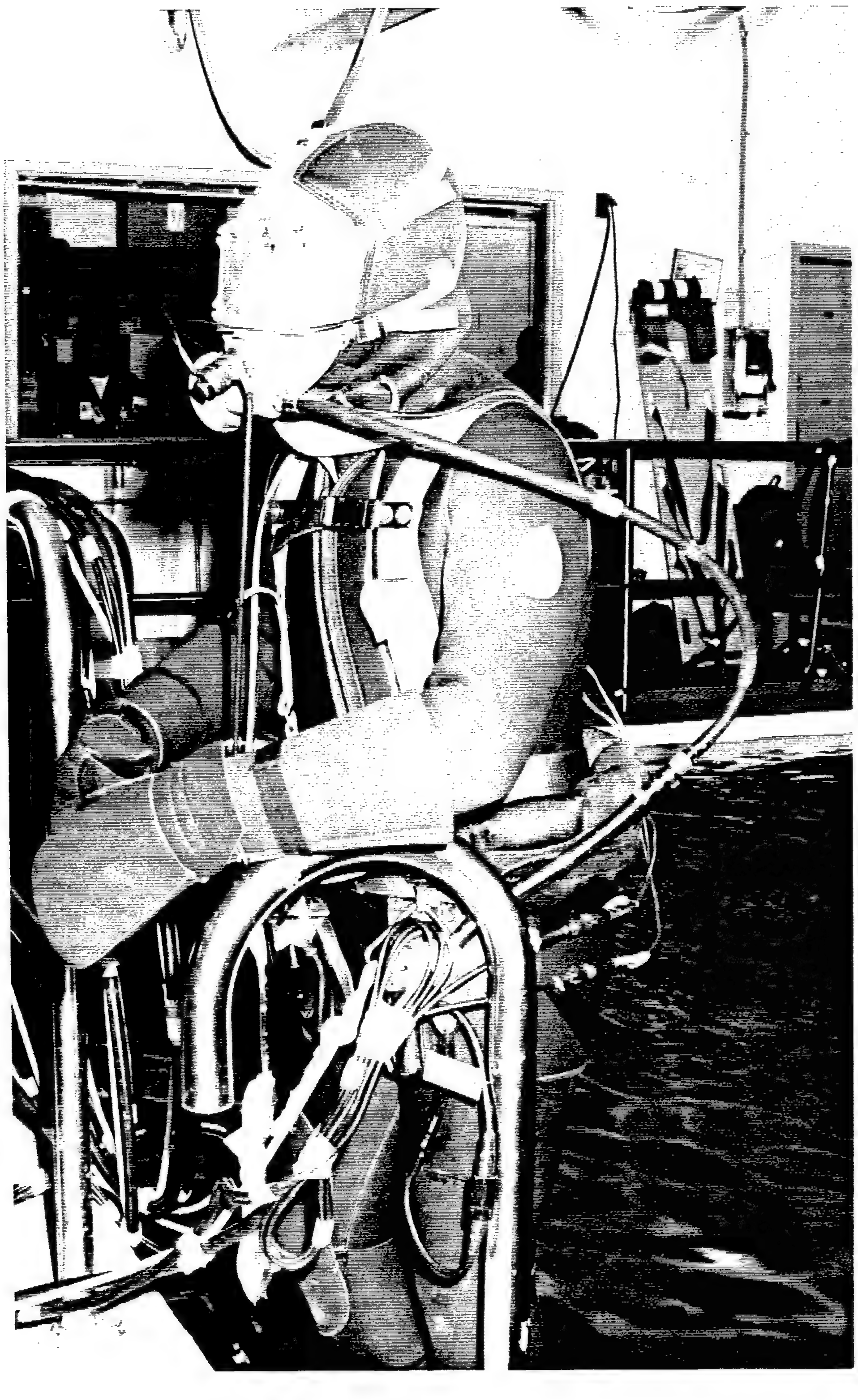
WET SUIT LAYERS

Note: The diver's final layer consisted of a <u>1/4" jacket, worn with a 1/4" hood</u>. Also notice the diver's 1/8" five-finger glove worn underneath the 1/4" outer "gauntlet" mitten.

WET SUIT GLOVES

Note: The diver's hand protection consisted of a 1/8" five-finger glove worn underneath a 1/4" outer "gauntlet" mitten.

WET SUIT LAYERS



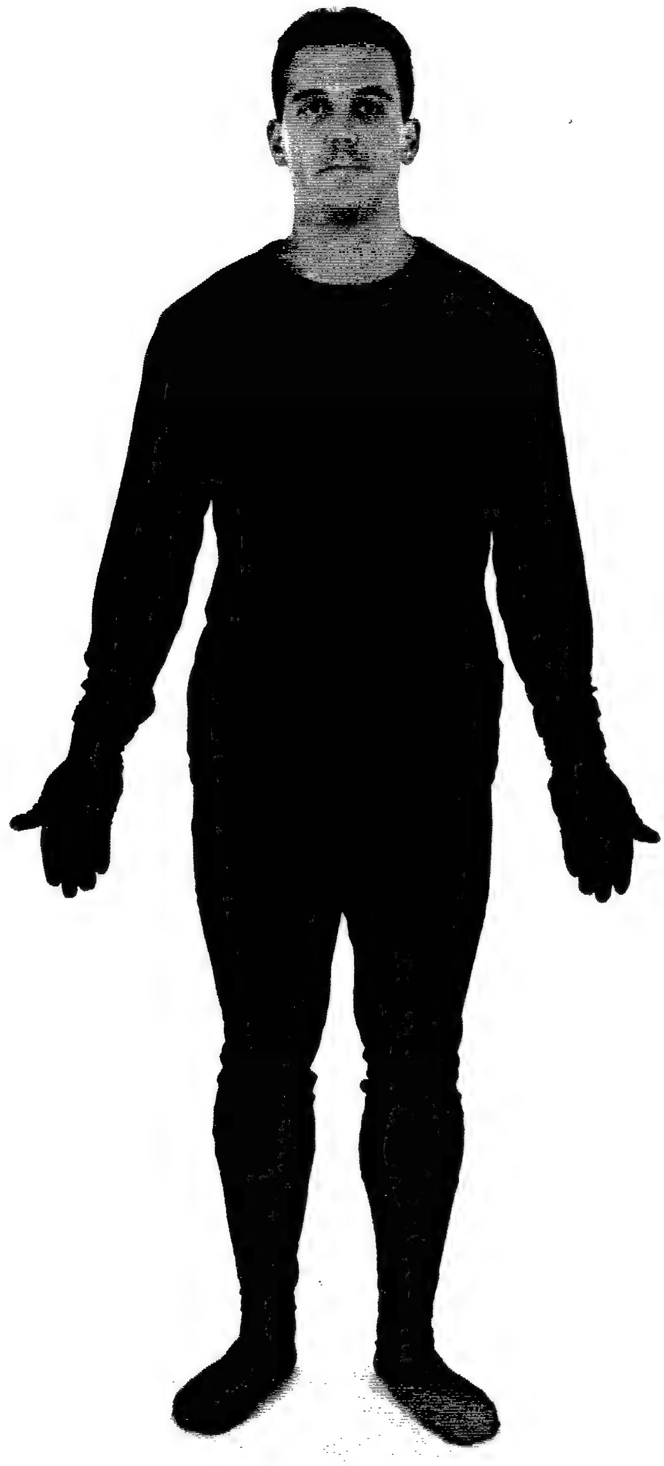
Note: The wet-suit diver fully dressed and instrumented - ready to enter the water.

2.) Viking Dry Suit

The Viking dry suit is the standard dry suit used by SDV Team 1. It was worn in the following layered manner described from the skin outward:

- 100% capilene polyester "lightweight" long underwear pants, crew-neck shirt, socks, and glove liners (the same long underwear was worn underneath all of the dry-suit ensembles).
- M600 thinsulate coverall, M400 thinsulate booties, M200 thinsulate hood, and M200 thinsulate 3-finger mitts. Thinsulate (3M Corporation) is a polypropylene fiber quilted between a nylon taffeta outer and inner fabric.
- Viking outergarment. This garment was a 2mm vulcanized rubber material with integral boots. The hood was also integral to the suit and was made of thin (<0.5mm) sheet rubber. The neck and wrist seals were thin (<0.5mm) sheet rubber. Suit inflation was with air from a pony bottle through an inlet on the lower left waist. A relief valve for controlling suit volume was installed on the left upper arm. The suit was altered at NMRI and an additional 3 suit penetrators were made to accommodate the following: 1) an EKG wire, 2) rectal and skin temperature wires, and 3) the cable for the electric suit (this penetrator was simply "blanked" when worn in the passive mode).
- Viking (dry) 3-finger mitts. These mitts are made of rubber and attach to the dry suit by a cuff ring system. In summary, the hands were covered with a 100% capilene glove liner, followed by an M200 thinsulate 3-finger mitt, followed by the outer dry Viking 3-finger mitt.
- An overboard urine collection system was utilized.

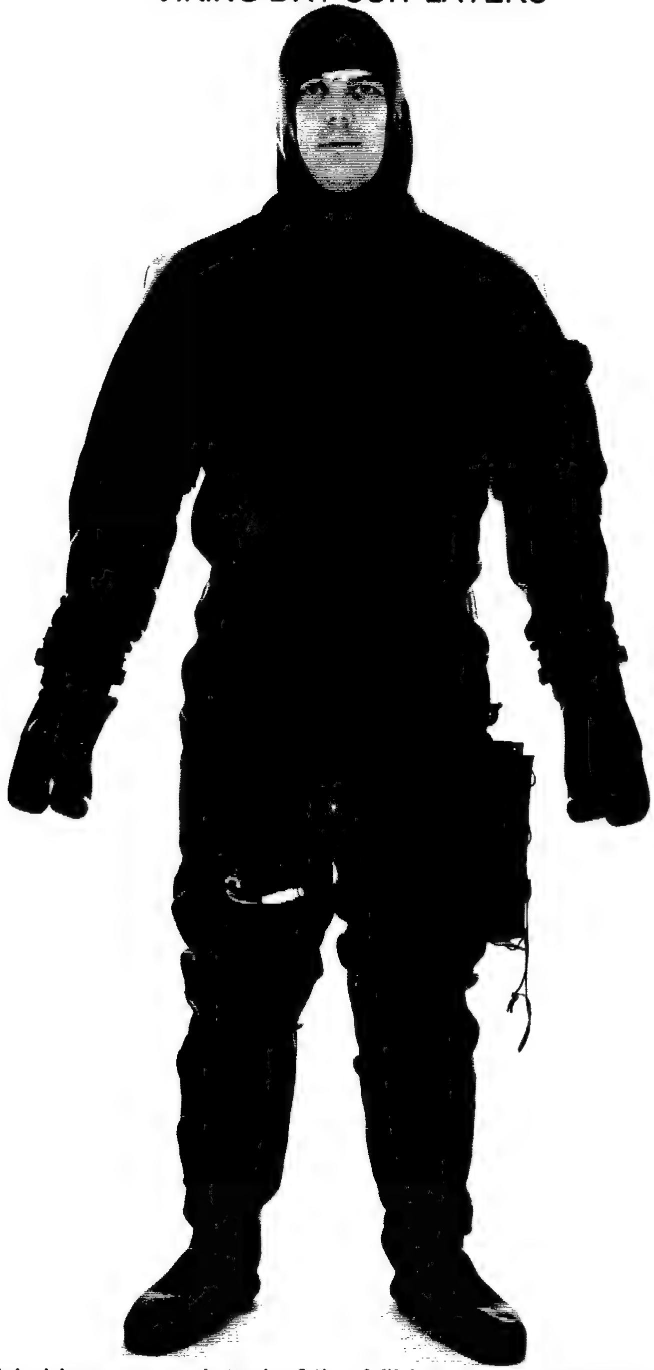
VIKING DRY SUIT LAYERS



Note: The diver's first layer consisted of 100% capilene polyester "lightweight" long underwear - pants, crew-neck shirt, socks, and glove liners.

Note: The diver's second layer consisted of a M600 thinsulate coverall, M400 thinsulate booties, M200 thinsulate hood, and M200 thinsulate 3-finger mitts.

VIKING DRY SUIT LAYERS



Note: The diver's third layer consisted of the Viking outergarment. This garment is made of a 2mm vulcanized rubber material with integral boots. The hood is also integral to the suit and is made of thin (<0.5mm) sheet rubber. The neck and wrist seals are thin (<0.5mm) sheet rubber. Suit inflation is with air from a pony bottle through an inlet on the lower left waist. A relief valve for controlling suit volume is installed on the left upper arm. The suit was altered at NMRI and an additional 3 suit penetrators were made to accommodate the following: 1) an EKG wire, 2) rectal and skin temperature wires, and 3) the cable for the electric suit (this penetrator was simply "blanked" when worn in the passive mode). Also, note the urine overboard dump tube in the upper right leg.

VIKING DRY SUIT LAYERS

Note: The Viking outergarment has a zipper entry across the upper back.

VIKING DRY SUIT GLOVES

Note: The diver's hand protection consisted of a 100% capilene glove liner, followed by an M200 thinsulate 3-finger mitt, followed by the outer dry Viking 3-finger mitt. The Viking (dry) 3-finger mitts are made of rubber and attach to the dry suit by a cuff ring system.

3.) SBS Dry Suit

The SBS SDV unit has a unique dry suit that they designed to best suit their needs. They conduct annual winter training in Norway and therefore recognize an operational need to be able to conduct long duration dives in 32 °F (0°C) water. In this study, the SBS dry suit was worn in the following layered manner described from the skin outward:

- 100% capilene polyester "lightweight" long underwear pants, crew-neck shirt, socks, and glove liners (the same long underwear was worn underneath all of the dry-suit ensembles).

- The dry-suit undergarment is custom manufactured (**Artkis Outdoor Products, 3 Brookside Industrial Estate, Exeter EX4 8JN, UK, phone number - 011-44-1-326-561-040)** for the SBS from quilted (150 gm/m^2) flectalon. Flectalon is a synthetic material made from strips of PVC sheet onto which a thin aluminum coating has been deposited which is then bulked and quilted. A nylon fabric is incorporated as an inner and outer liner. This flectalon garment is fashioned into a coverall with booties attached. An additional flectalon vest and overbooties were worn over the coverall. There was no flectalon hood. The SBS flectalon garment was clearly thicker and heavier than the M600 thinsulate.

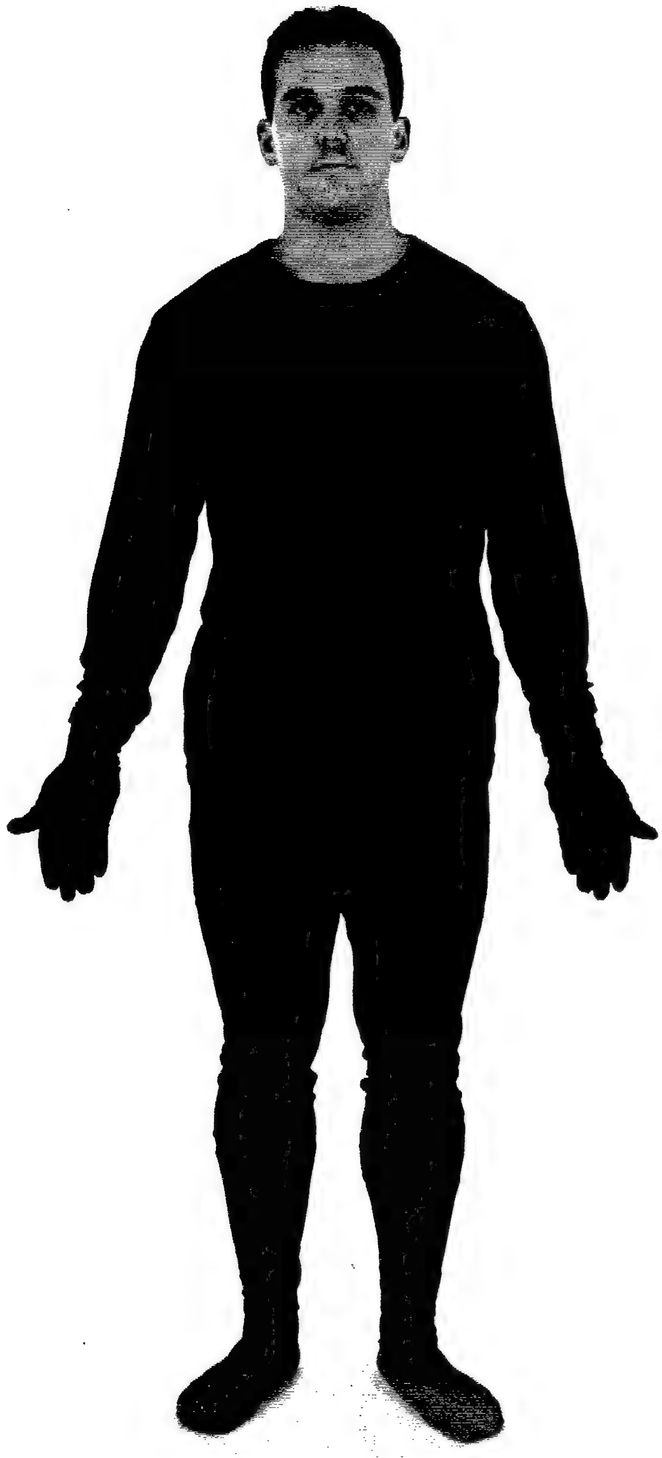
- On the hands, worn over the capilene glove liners, were (5-finger) ski gloves with thinsulate insulation layers and an outer Gore-tex shell.

- A neoprene dry-suit outergarment was worn **(Artkis Outdoor Products, 122/128 Lake Rd., Portsmouth, PO1 4HH, UK, phone number - 011-44-1-705-814-924).** This garment was 8.5 mm neoprene throughout the entire garment with an integral hood and boots. The neck and wrist seals were tapered to 3 mm and 7 mm, respectively, and had a smoothed/polished neoprene finish to facilitate water-tight sealing. Suit inflation was with air from a pony bottle through an inlet on the upper right leg. A relief valve for controlling suit volume was installed on the right lower arm. The suit was altered at NMRI and an additional 2-suit penetrators were made to accommodate an EKG wire, and another for rectal and skin temperature wires. These penetrators were placed along the back in the subscapular position. The outergarment had a built-in penetrator for the urinary dump system.

- The dry-suit overmittens were 8 mm neoprene and were a thumb and 4-finger mitt configuration. The mitts attached to the dry suit by fitting tightly over a large cuff and were secured with rubber straps.

- An overboard urine collection system was utilized.

SBS DRY SUIT LAYERS

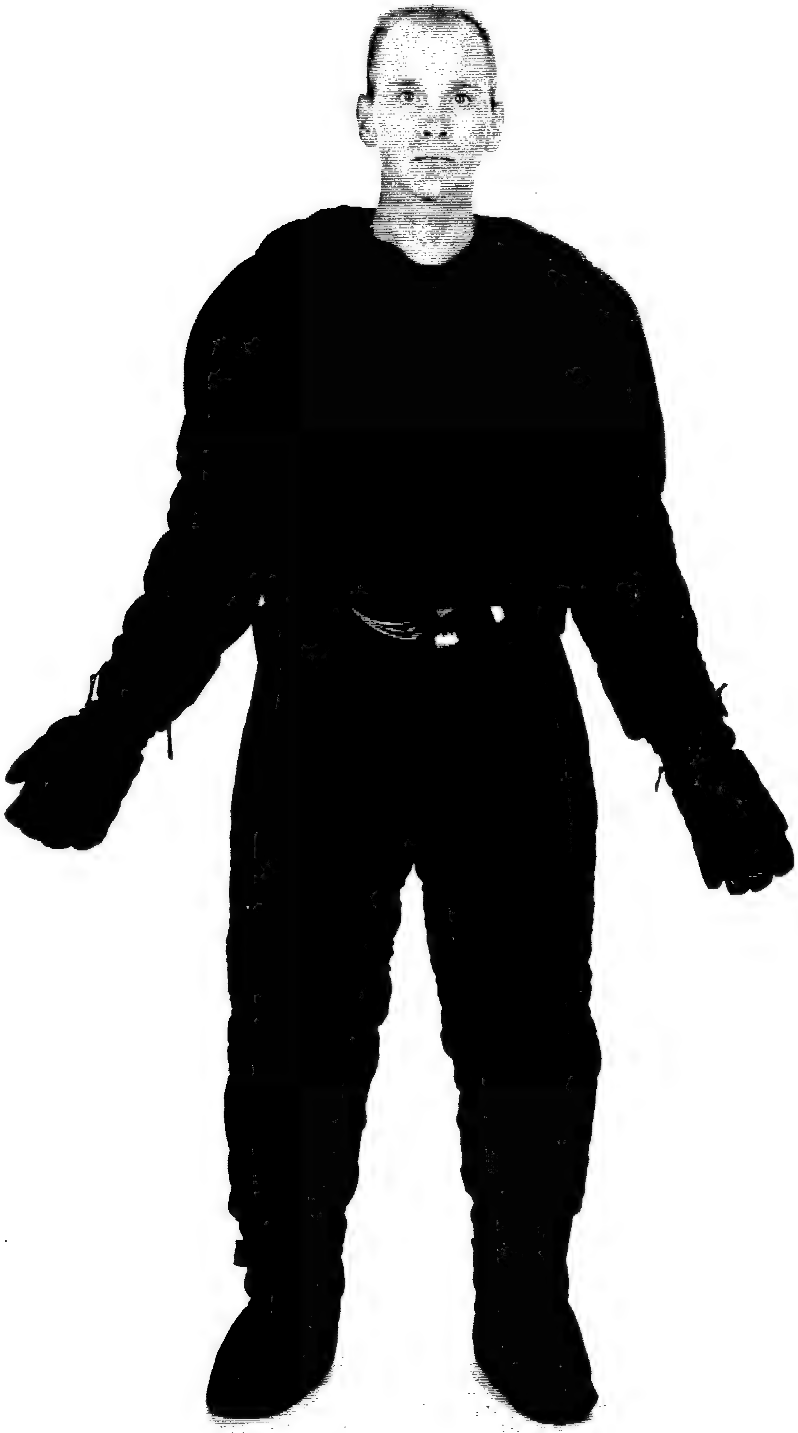


Note: The diver's first layer consisted of 100% capilene polyester "lightweight" long underwear - pants, crew-neck shirt, socks, and glove liners.

SBS DRY SUIT LAYERS

Note: The diver's second layer consisted of a custom-made flectalon coverall with booties attached. Also note the ski gloves worn on the hands.

SBS DRY SUIT LAYERS



Note: The diver's third layer consisted of an additional flectalon vest and overbooties worn over the coverall. Note that there was no flectalon hood. Note that the SBS flectalon garment is visibly thicker and heavier than the M600 thinsulate.

SBS DRY SUIT LAYERS

Note: The diver's fourth layer consisted of a neoprene dry-suit outergarment. This garment was 8.5 mm neoprene throughout the entire garment with an integral hood and boots. The neck and wrist seals were tapered to 3 mm and 7 mm, respectively, and had a smoothed/polished neoprene finish to facilitate water-tight sealing. Suit inflation was with air from a pony bottle through an inlet on the upper right leg. A relief valve for controlling suit volume was installed on the right lower arm. Note the built-in penetrator for the urinary dump on the inner right leg/thigh of the outergarment.

SBS DRY SUIT LAYERS

Note: The dry-suit overmittens were 8 mm neoprene and were a thumb and 4-finger mitt configuration. The mitts attached to the dry suit by fitting tightly over a large cuff and were secured with rubber straps.

SBS DRY SUIT LAYERS

Note: The suit was altered at NMRI and an additional 2 suit penetrators were made to accommodate an EKG wire and another for rectal and skin temperature wires. These penetrators were placed along the back in the subscapular position.

SBS DRY SUIT GLOVES

Note: The diver's hand protection consisted of a 100% capilene glove liner, followed by (5-finger) ski gloves with thinsulate insulation layers and an outer Gore-tex shell. Lastly, the dry-suit overmittens were 8 mm neoprene and were a thumb and 4-finger mitt configuration. The mitts attached to the dry suit by fitting tightly over a large cuff and were secured with rubber straps.

4.) Electric Suit **(the Exotemp manufactured by Carleton Technologies, Inc., 3910 Riga Blvd., Tampa, FL, 33619-1344, phone number - 813-623-3711).**

This suit is currently not in use by any SDV units, but was chosen after an extensive market survey and because of its success in test dives done at the DCIEM in Toronto, Canada, and because of its potential for use in an SDV application.

The Exotemp electric suit is a one-piece whole-body suit made of a stretchy lightweight knit fabric (with virtually no inherent insulation) with non-magnetic (when not activated) heavy gauge stranded heating/resistance wire stitched continuously throughout the suit. Electric gloves, wired in series with the suit, were also worn. These gloves had a smaller gauge wire woven into the palm and dorsal surfaces of the hand and fingers. There were no wires along the palmar aspects of the fingers in order to enhance manual dexterity. The electric suit was connected to a 30-foot electrical cable/tether through a water-tight penetrator in the Viking dry suit.

A topside power supply located at the other end of the cable/tether was used to set the current through the suit and gloves. This supply also incorporated circuitry to trip on ground fault, overcurrent, and overvoltage. At NMRI we also incorporated a diver controlled cut-off switch.

The Exotemp electric suit was worn over the diver's long underwear and under his thinsulate coverall and Viking dry-suit outergarment. In short, the electric suit was simply added to the exact same ensemble as the Viking dry suit (as described above).

The following terms and equations will be used to discuss the electric suit:

Potential = V = volts | Current = I = amps
Power = P = watts | Resistance = R = ohms
Ohm's law - $V = I \times R$ | Power equation - $P = I \times V = I^2 \times R$
Resistance in parallel = $1 / (1/R_1 + 1/R_2 + 1/R_3)$
Resistance in series = $R_1 + R_2 + R_3$

The following basic facts apply to our application of the electric suit:

- The resistance of the electric suit was 0.4 ohms/segment. The suit contains four parallel segments. Therefore, the total suit resistance equals 0.1 ohms.

- The power delivered to the suit equals the current squared times the resistance of the suit (I^2 (x) R_S).

For the dives in 36.5°F water the power delivered to the suit from the power supply was (50^2 (x) 0.1) 250 watts.

For the dives in 55°F water the power delivered to the suit from the power supply was (35^2 (x) 0.1) 122.5 watts.

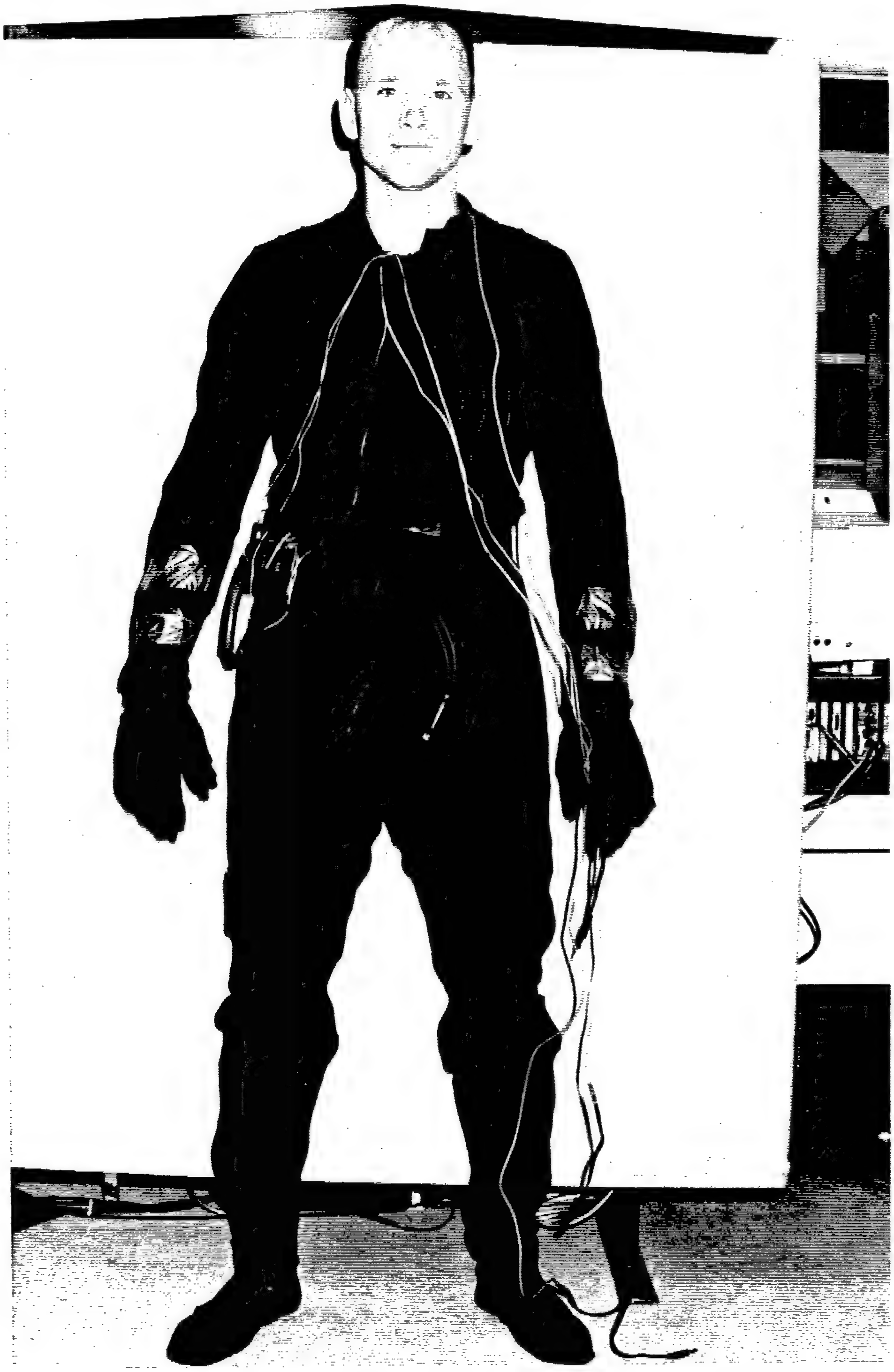
- The 30-foot cable had an approximate resistance of 0.43. Therefore, the power loss due to the cable was approximately equal to I^2 (x) 0.043.

The following table represents all the settings used during the experimental dives in 36.5°F water:

Power Supply Voltage	Power Supply Current	Power Supply Wattage	Wattage delivered to the Suit	Cable Loss
7.2 v	50 amps	360 w	250 w	~110 w

The following table represents all the settings used during the experimental dives in 55°F water:

Power Supply Voltage	Power Supply Current	Power Supply Wattage	Wattage delivered to the Suit	Cable Loss
5.0 v	35 amps	175 w	122.5 w	~52.5w



Note: The Exotemp electric suit is a one-piece whole-body suit made of a stretchy lightweight knit fabric with non-magnetic (when not activated) heavy gauge stranded heating/resistance wire stitched continuously throughout the suit. Electric gloves, wired in series with the suit were also worn. These gloves had a smaller gauge wire woven into the palm and dorsal surfaces of the hand and fingers. There were no wires along the palmar aspects of the fingers in order to enhance manual dexterity. The Exotemp electric suit was worn over the diver's long underwear and under his thinsulate coverall and Viking dry-suit outergarment. In short, the electric suit was simply added to the exact same ensemble as the Viking dry suit (as described above).

ELECTRIC SUIT LAYERS

Note: The diver is holding the connection of the electric suit to a 30 foot electrical cable/tether that passes through a water-tight penetrator in the Viking dry suit.

A topside power supply located at the other end of the cable/tether was used to set the current through the suit and gloves. This supply also incorporated circuitry to trip on ground fault, overcurrent, and overvoltage. At NMRI we also incorporated a diver controlled cut-off switch.

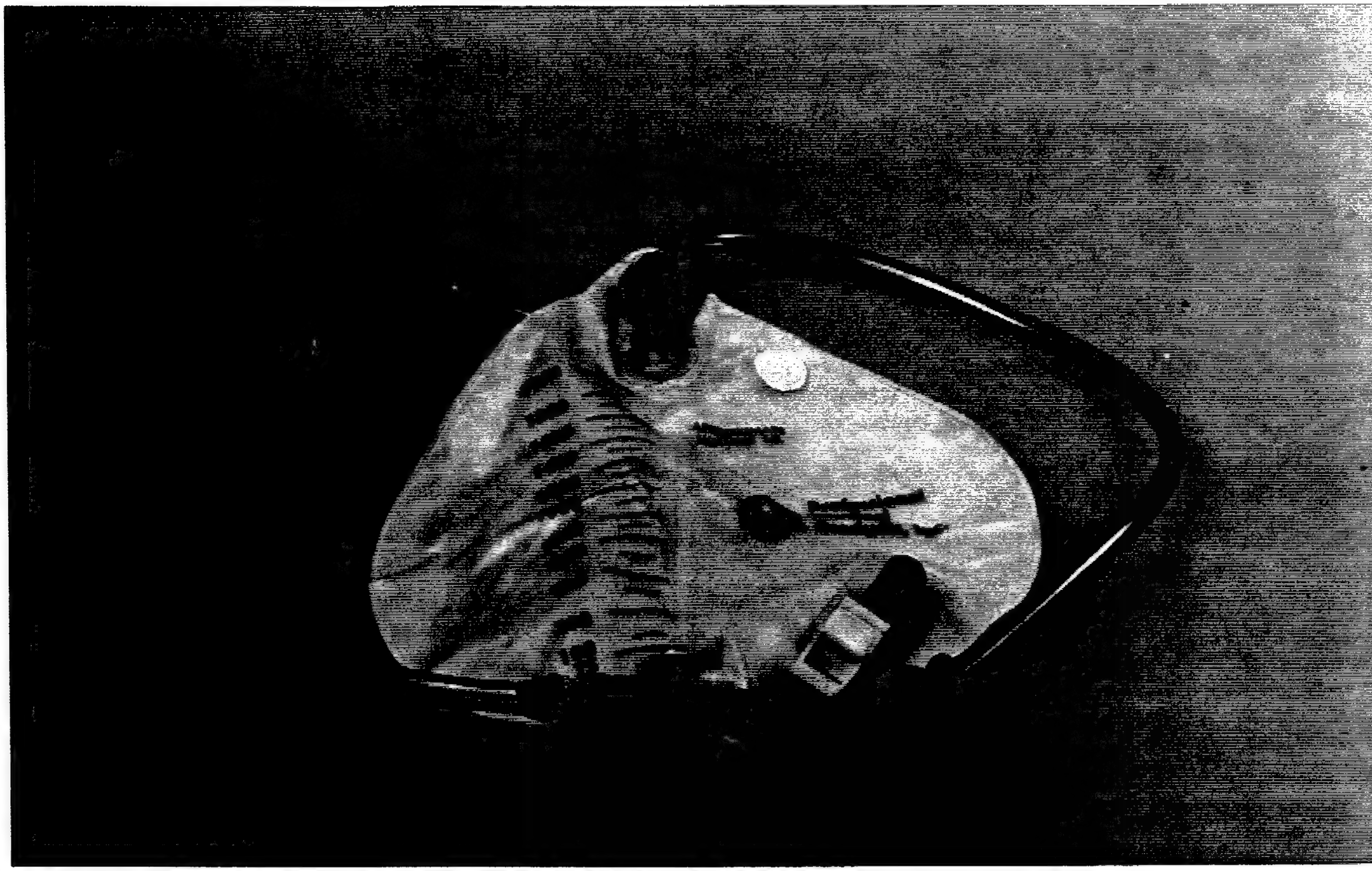
ELECTRIC SUIT LAYERS

Note: The electric suit diver completely dressed and prepared to enter the water.

ELECTRIC SUIT GLOVES

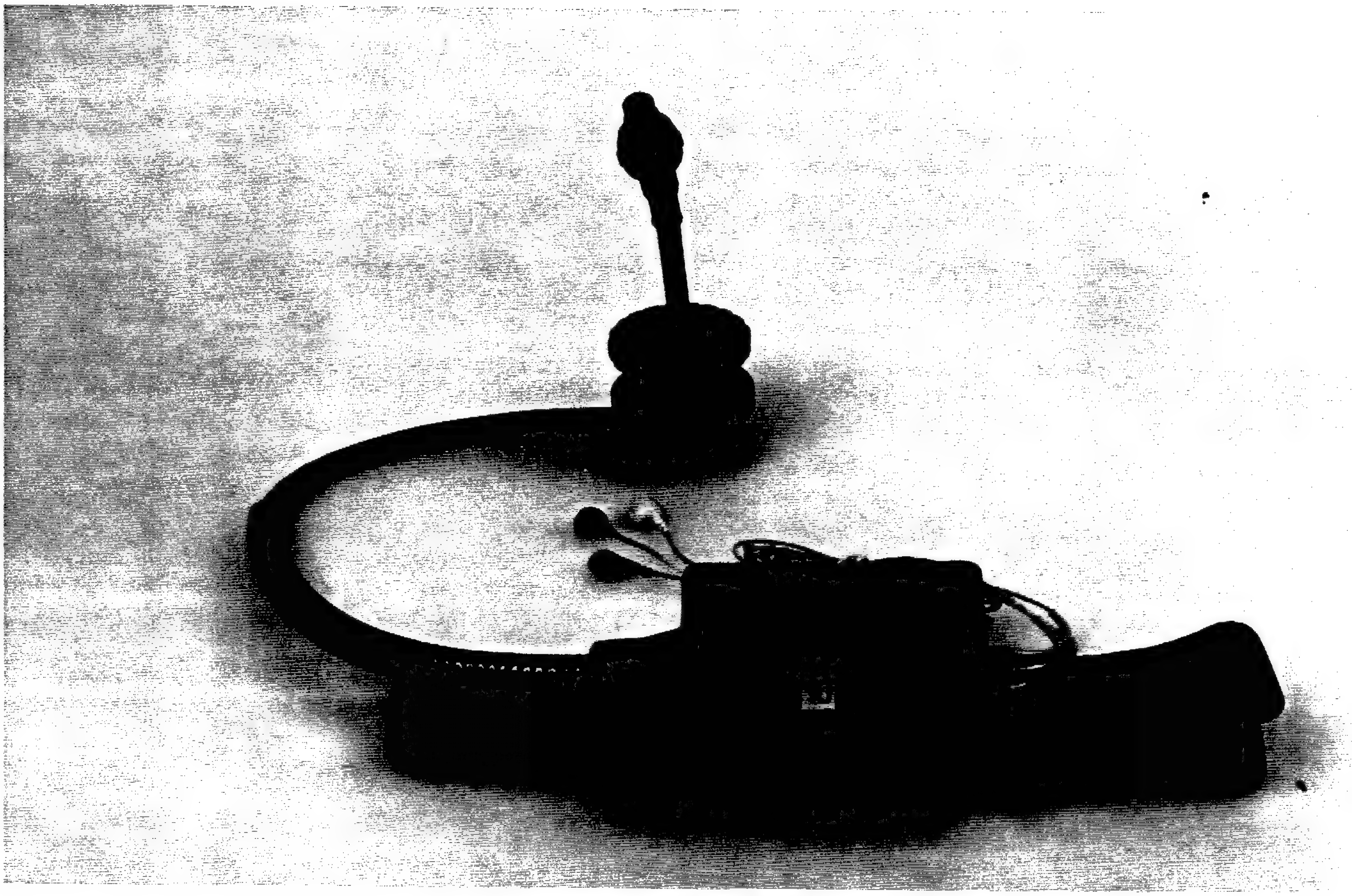
Note: The diver's hand protection consisted of a 100% capilene glove liner, followed by an electrically heated glove, an M200 thinsulate 3-finger mitt, and lastly the outer dry Viking 3-finger mitt. The Viking (dry) 3-finger mitts are made of rubber and attach to the dry suit by a cuff ring system.

URINE EXCRETION SYSTEM



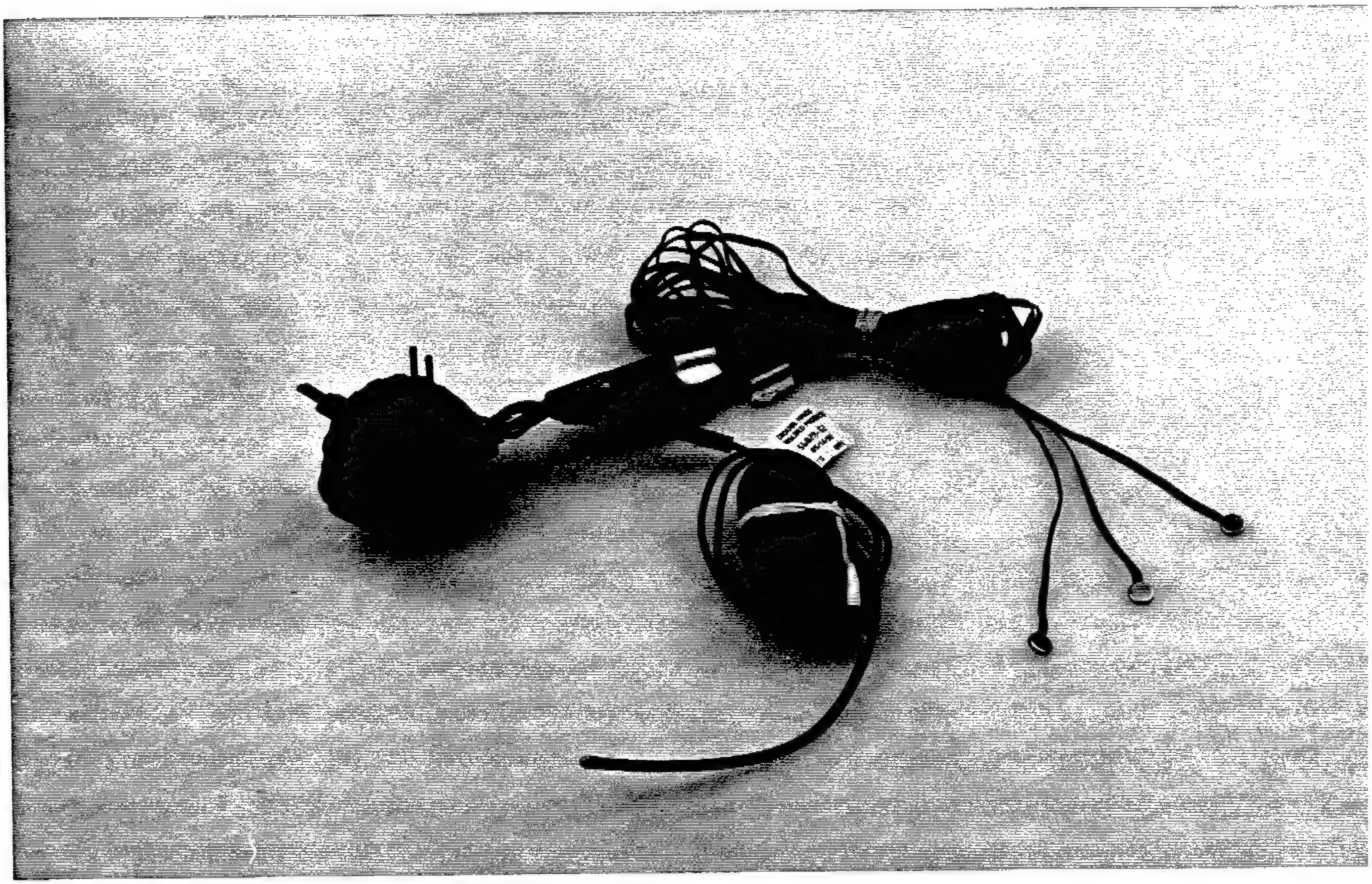
Note: A urine excretion system was used with all of the suits, including the wet suit. It consisted of a self-adhesive incontinence sheath, a quick disconnect with one way valve, and interconnecting tubing. The head of the penis was inserted against the sealing diaphragm of the incontinence sheath and the sheath unrolled up the shaft where the adhesive held it in place. All dry-suit outer garments had tubing and a penetrator either already installed (in the SBS suit) or installed by us at NMRI (in the Viking dry suit). After inserting their legs into the outer garment, the penile sheath with a quick disconnect attached was connected to tubing inside the dry suit. This tubing ran through a dry suit penetrator and was attached on the outside of the dry suit with another quick disconnect to more tubing and a collapsible urine collection bag. In the case of the wet suit a suit penetrator was obviously not necessary.

EKG MEASUREMENT



Note: A NMRI developed electrically isolated and waterproofed EKG amplifier gave a continuous topside readout of heart rate and rhythm.

TEMPERATURE MEASUREMENT



Note: Temperature measurement was accomplished with YSI (Yellow Springs Instrument Co., Inc., Yellow Springs, Ohio, 45387) rectal and skin temperature probes. These probes were run through a dry-suit penetrator and then integrated into the diver's umbilical. Topside measurement of real time rectal and finger skin temperatures were recorded.

APPENDIX B

EXPLANATION OF PERFORMANCE TESTS

Performance Measures

This research study focused on performance as the key measure of success of one thermal garment over another. The two performance measurement systems were the Systematic Investigation of Diver Behavior At Depth (SINDBAD), in-water performance measurement system, and the Special Operations Forces Performance Assessment Battery (SOF PAB), dry/land-based performance tests of SOF mission-related tasks.

SINDBAD

The SINDBAD performance test battery was developed by the U.S. Navy in the late 1960s to provide a comprehensive method of testing human performance in a hyperbaric and/or underwater environment.[11,12] It was successfully tested and evaluated at the Naval Experimental Diving Unit (NEDU) in 1974[13], and since then has been used in many diving studies.

The SINDBAD system as used in this dive study consists of two main components:

a. a computer, which was located topside and was used to administer the tests and record the scores;

b. an underwater module on which the diver, using a magnetized "pen" or magnetized tools, recorded his answers. The underwater module is a sealed unit on the face of which is a series of "cells." These cells contain light emitting diodes that have the ability to display numerals or the standard mathematical signs (+, -, /, x). Additionally, some cells are square and others are circular. All cells are activated by the insertion of a magnetic "pen" or tool into them.

Using this system, seven performance tests were done underwater by each diver every two hours during each experimental dive. The series of seven tests took approximately 20 - 30 minutes to complete. Baseline tests were done both on land with nothing on the hands (i.e., no gloves) and then again in the water before any lengthy cold exposure with each of the thermal garments. Therefore, four baseline scores were obtained: 1) dry/land baseline, 2) wet-suit baseline, 3) Viking dry-suit baseline and 4) SBS suit baseline. The electric suit had the same glove configuration as the Viking dry suit, except for a very thin spandex glove with wires woven only onto the dorsal aspect of the hand. Therefore, it was determined that the Viking dry-suit baseline scores would apply to the electric suit as well.

The 7 SINDBAD tests consisted of 3 tests of manual dexterity and 4 tests of cognitive ability. They are explained in detail below, in the order in which the diver performed the tests:

1) Key Insertion Test (B1)

This test of finger dexterity utilized a special tool that had a magnet at each end. The two ends were of different shapes -- one was round and the other square. The diver was required to alternately insert the round end into the designated round cell on the underwater module, and the square end into the designated square cell. The score was the number of alternate insertions achieved in 60 seconds.

2) Wrench and Cylinder Test (B2)

This test of manual dexterity involved the use of a special tool that, with square and round ends, mounted inside a cylinder. Only one end of the tool could be exposed from the cylinder at any one time, the ends being changed by screwing the tool with a specially designed wrench. The aim of the test was to alternate square and round responses, screwing the tool with the wrench between each response. The score was the number of alternate responses in a 2-minute period.

3) Stylus Test (B3)

This test of tapping and aiming required the repeated rapid tapping of one end of the magnetized stylus/pen into a single cell on the underwater module. The score was the number of insertions achieved in a 30-second period.

4) Visual reaction time test (C1)

This test of reaction time required the diver to, as quickly as possible, remove the pen from a designated cell, where he had previously placed it, in response to a stimulus. The score was the mean reaction time for 20 trials.

5) Time Reproduction Test (D1)

This test of time estimation required the diver to estimate the duration a light was displayed and then reproduce that time by holding the stylus/pen in a designated cell for the same amount of time. The diver was given a 1-, 2-, 4-, 8-, 16-, 32-, and 64-second stimulus in random order on every test. The score was the average percent time error, with a negative number meaning that the time estimation was, on the average, shorter than the actual stimulus time.

6) Visual Digit Span Test (I1)

This test of memory required the diver to reproduce a series of numbers displayed to him immediately prior to his response (like remembering a phone number). The number of digits increased after each correctly answered trial. The score was the longest correct digit series.

7) Operations Test (K1)

This test of general reasoning required the diver to provide the correct mathematical operation that related 2 numbers to a third number (the "answer"). For example, the 3 numbers might be 43, 8, and 51, and the correct response would be "+" (addition). The diver's score was the total number of correct answers (out of a total of 20 problems) and the average reaction time to answer each problem.

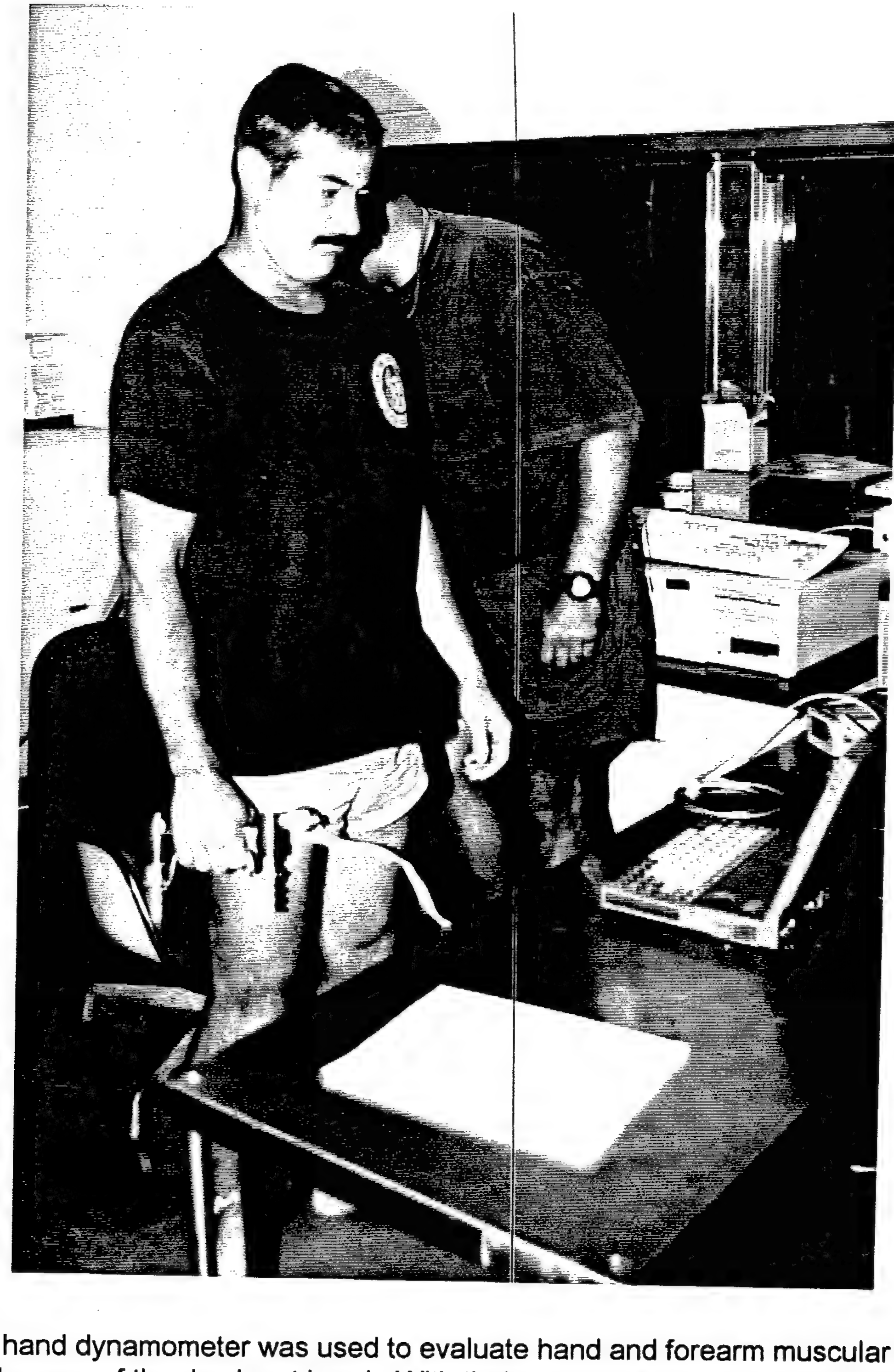
SOF PAB

The SOF PAB was developed by NMRI in response to a USSOCOM tasking to standardize performance measures used in USSOCOM sponsored research.[14] As such, this series of performance tests was used in this study to evaluate the relative efficacy of each thermal garment. The idea being that if one thermal garment is significantly better than another, then this benefit should be reflected in an improved performance.

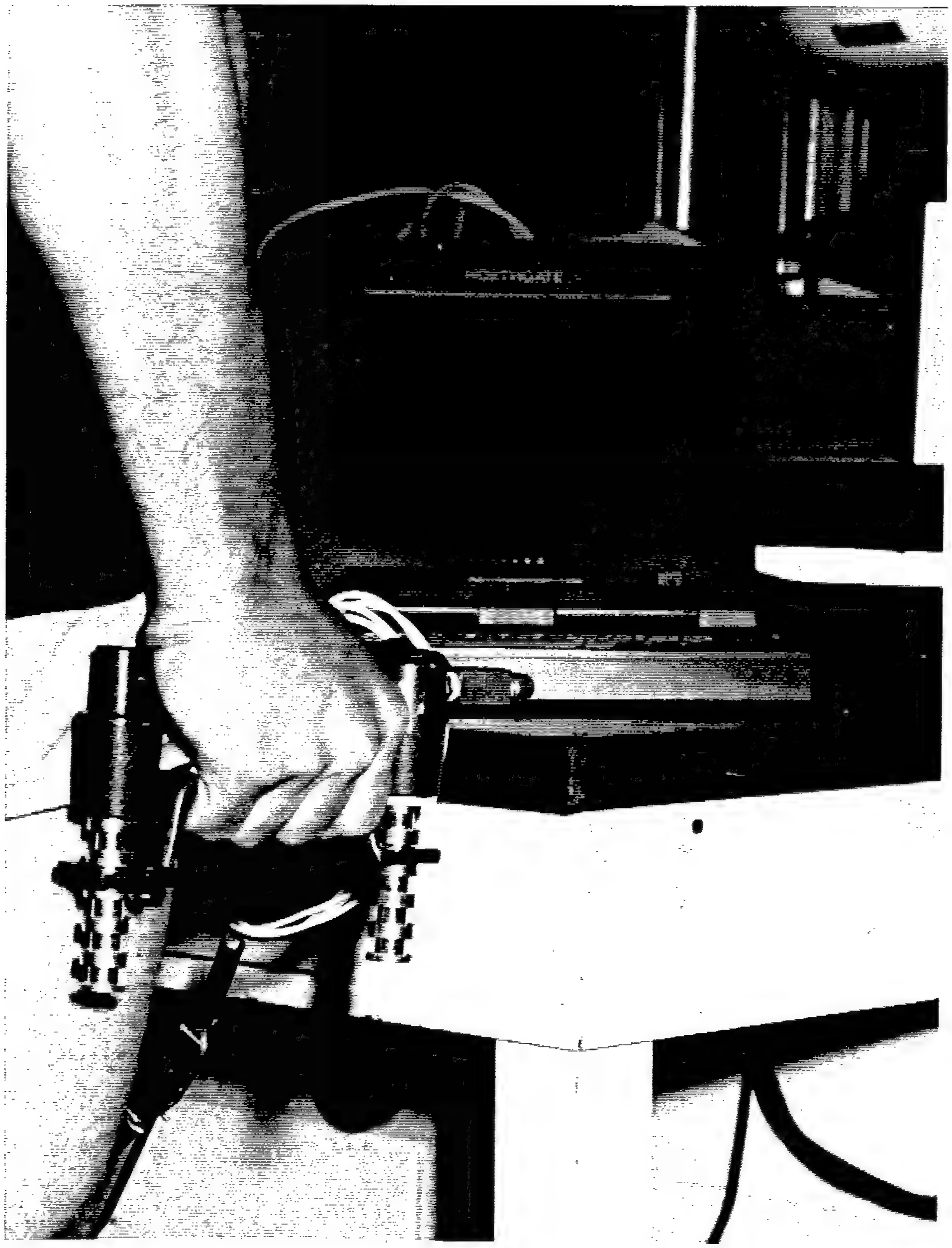
The SOF PAB consists of 5 physiological tests and 6 cognitive tests designed to test SOF mission-related tasks. These tests were performed by each diver immediately after each experimental dive. The complete SOF PAB took approximately 30 - 45 minutes to complete (~ 15 minutes for the physiological tests and ~ 15 - 30 minutes for the cognitive tests). Multiple baseline tests were done during the work-up phase of this study during times when the divers were well rested and not under thermally stressful conditions.

The 5 physiological tests evaluate strength, endurance, fine and gross motor skills, eye-hand coordination, and vision. The tests are listed below in the order in which they were performed both before and after the experimental dives.

SOF PAB
MAXIMAL HAND-GRIP FORCE AND ENDURANCE TEST



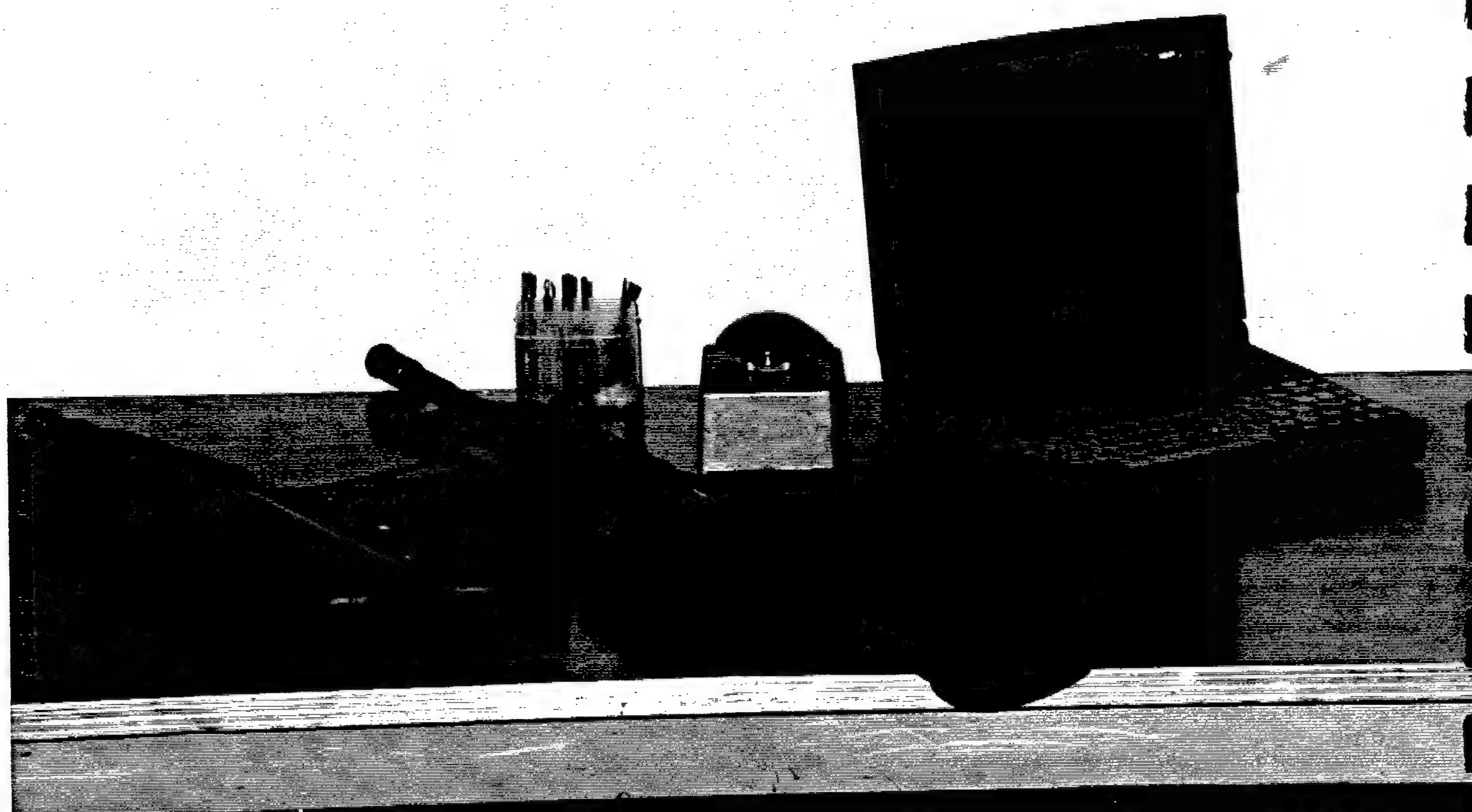
Note: A hand dynamometer was used to evaluate hand and forearm muscular strength and endurance of the dominant hand. With their arm and hand hanging by their side, divers were instructed to squeeze the dynamometer as hard as possible, thus exerting a maximal contraction of the hand. Maximal hand-grip strength was recorded from the dial indicator on the dynamometer.



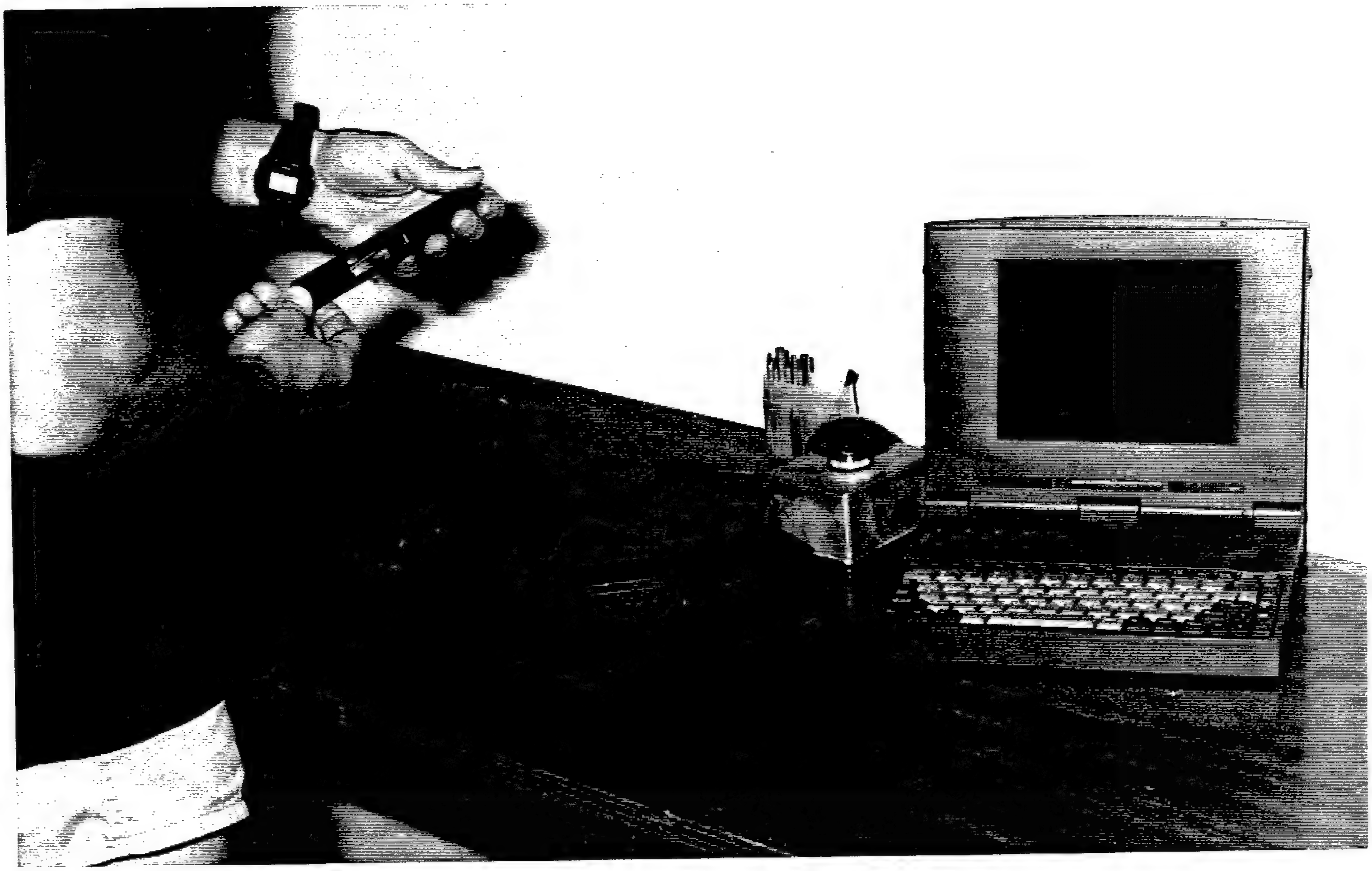
Note: The digital output on the dynamometer was connected to a lap-top computer and allowed a real-time display of the dynamometer output on the computer screen. Once a maximal hand-grip force was established, values equal to 45% and 55% of maximum were automatically calculated by the computer and displayed in real time on the computer screen. These values comprised the lower and upper limit "window," which the divers were instructed to maintain. This involved instructing the divers to relax their contraction until it was within the 45-55% window and maintain that level for as long as possible. Therefore, the score for this test was the maximal hand-grip force attained (in pounds per square inch (psi)) and then the amount of time (in seconds) that the contraction was maintained within the 45-55% (of maximum) window.

SOF PAB

DISASSEMBLY AND REASSEMBLY OF A WEAPON TEST

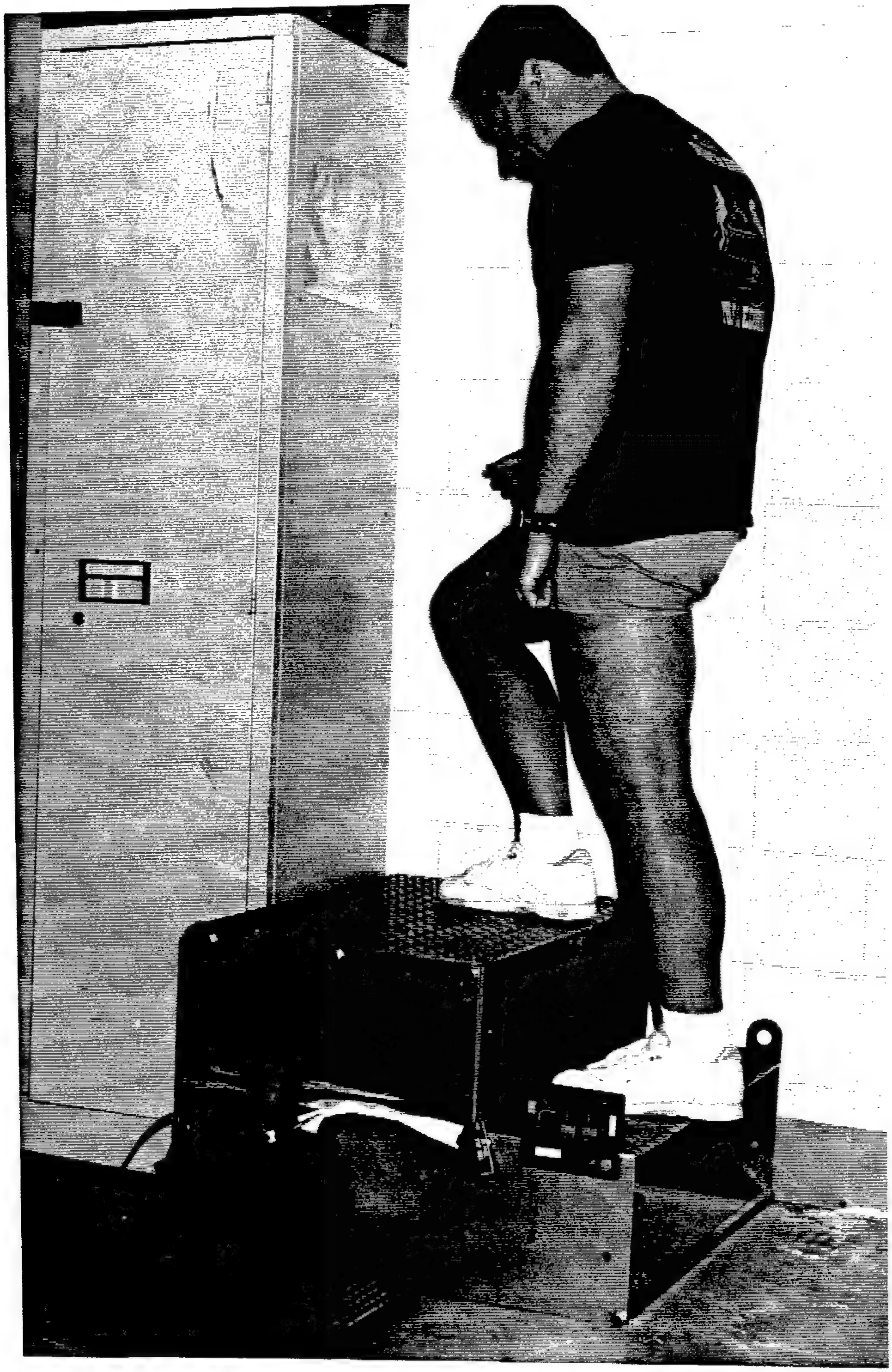


Note: This test was designed to evaluate fine and gross motor skills of the fingers, hands, and arms. Adequate re-familiarization and consistent performance with the weapon was established prior to the task being performed for a recorded time. Divers disassembled and reassembled either an M-16 (Model 727, carbine, 5.56 mm) or an HK-MP5 (Navy Model, submachine gun, 9 mm), depending on personal preference. The task was timed by a timing device connected to a computer that was activated to indicate the beginning of the disassembly and the end of the reassembly.



Note: The level of disassembly was established prior to the experimental dives, consisted of "field-stripping" the weapon, and was kept consistent throughout the study. The score was the total number seconds it took to disassemble and reassemble the weapon.

SOF PAB
MAXIMAL REPETITIONS DURING A TIMED STEP TEST

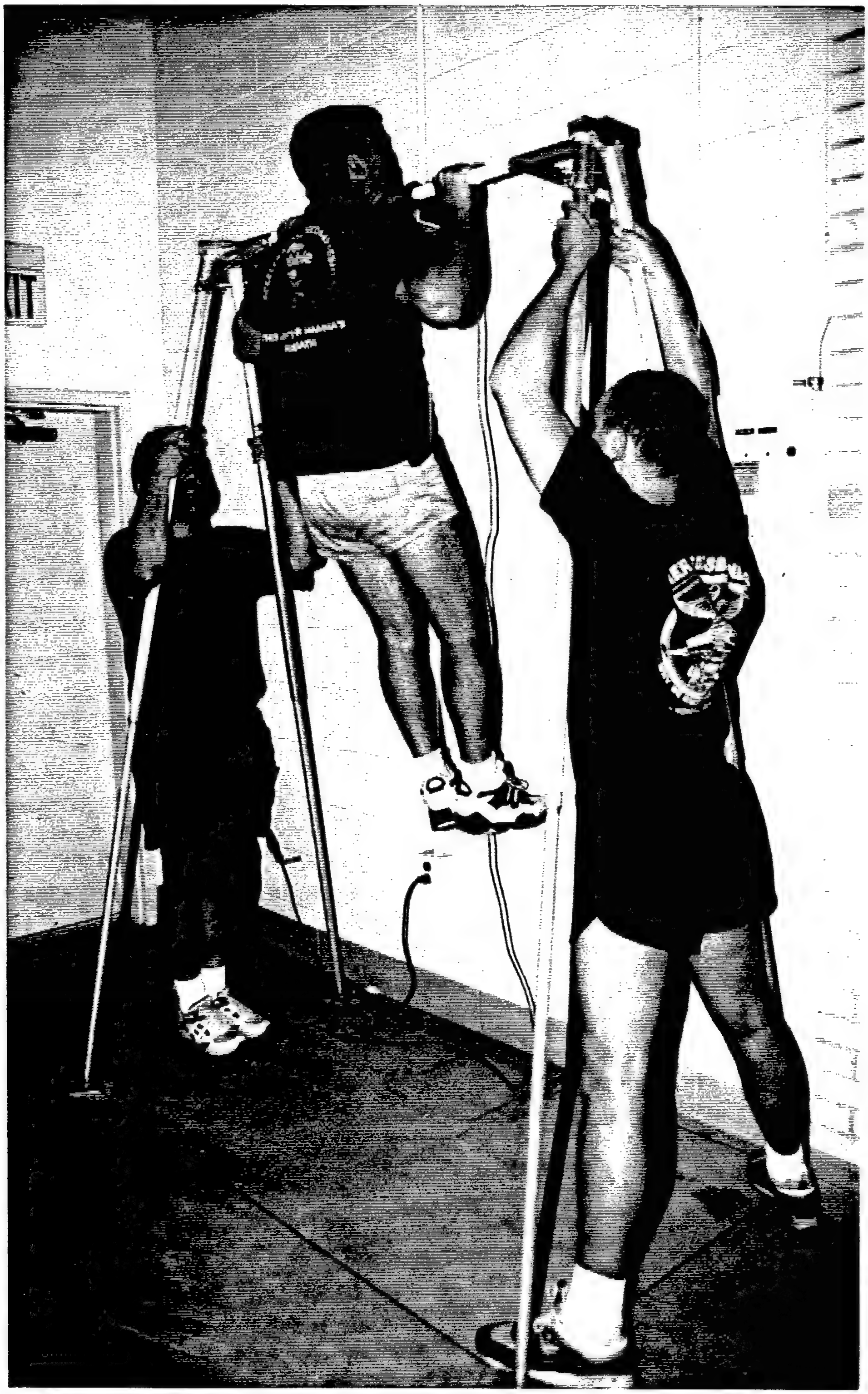


Note: This test was designed to evaluate lower body mobility, coordination and strength. Divers mounted and dismounted a set of steps as many times as possible for a period of 60 seconds. The number of cycles was timed and recorded (using a laser motion detector) by computer. The steps used are of the standard Harvard Step Test variety (two steps, each ten inches in height, for a total of twenty inches vertical rise).

SOF PAB
MAXIMAL REPETITIONS DURING A TIMED STEP TEST (CONT.)

Note: Safety spotters ensured the safety of the diver/subject. The score was the total number of steps climbed in 60 seconds.

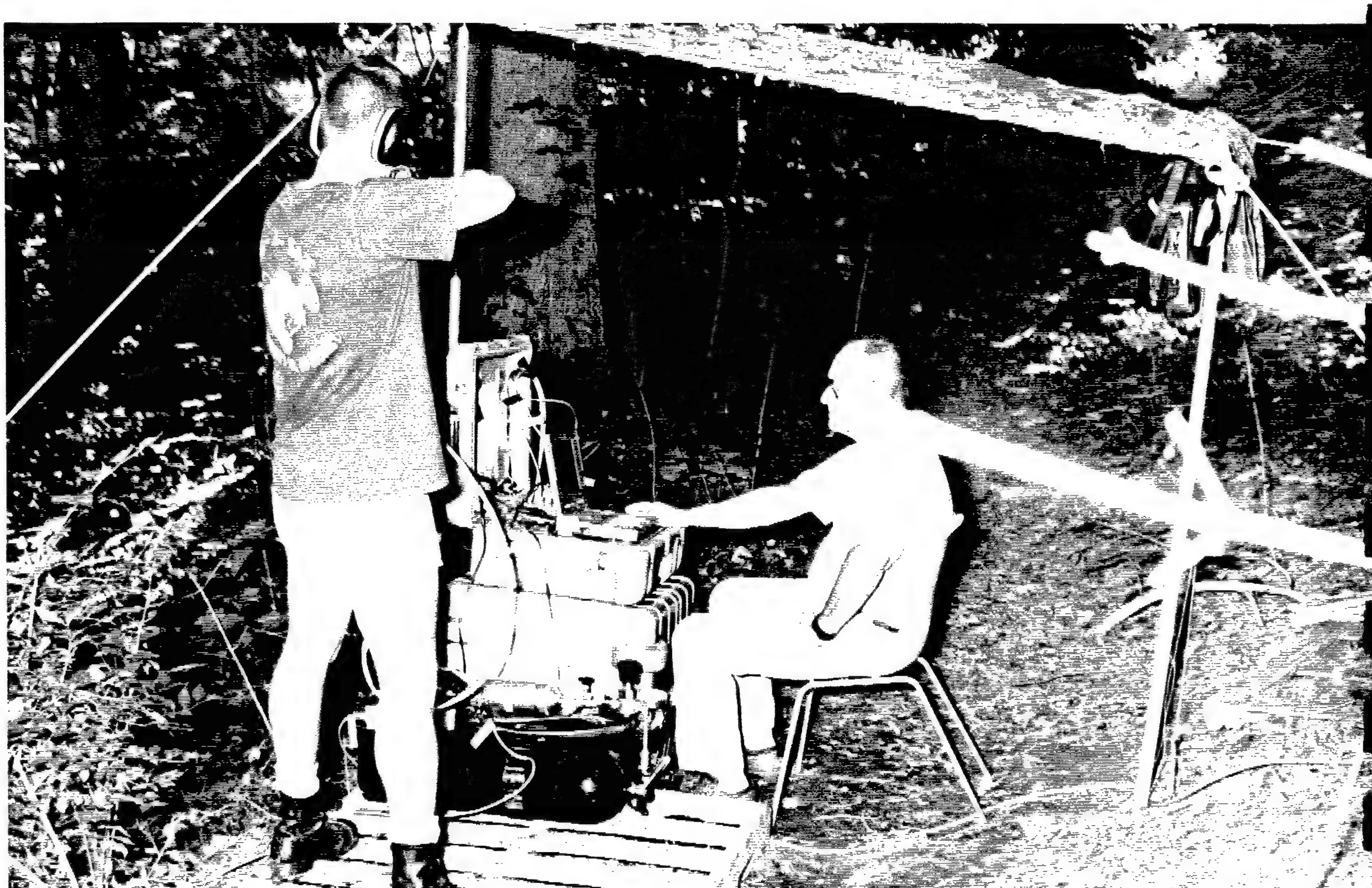
SOF PAB
MAXIMAL PULL-UPS TEST



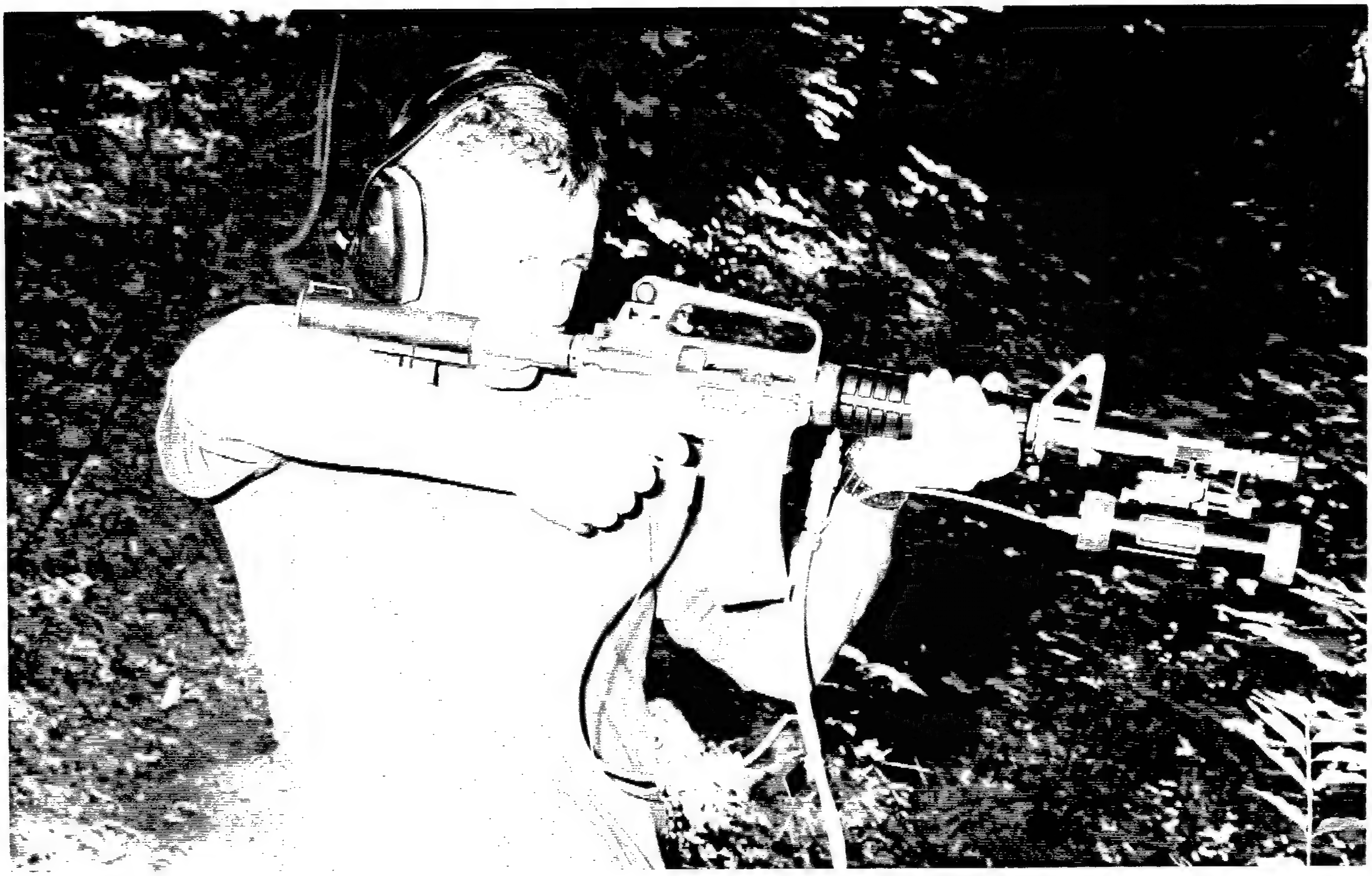
Note: This test was designed to test upper body strength. Divers simply performed a maximal number of pull-ups.

SOF PAB
MAXIMAL PULL-UPS TEST (CONT.)

Note: The number of pull-ups was objectively "counted" by a device mounted on the bar that was activated by the chin, once over the bar, depressing it. This count was then recorded by computer. The score was the total number of pull-ups done in an unlimited amount of time (once the bar was dismounted however, the test ended).



Note: This test was designed to test fine and gross motor skills, eye-hand coordination, vision, and attention. Specially modified M-16s were used to assess the ability of subjects to quickly acquire and hit a series of pop-up targets. Weapons were modified to operate pneumatically (no ammunition or blanks were used) using a portable pressurized gas system (gas supplied by SCUBA tanks) in a semi-automatic firing configuration.



Note: The firing of a shot was simulated by a laser system activated by the trigger pull of the weapon.

Note: Reflective targets return the laser beam to the receiver on the weapon if a hit is scored. The position of the eight pop-up targets, the duration of presentation, the interval between target presentations and the total number of targets presented (there was a total of 25 targets presented) were constant. Only the order of target presentation was randomized. The score reflects the total number of targets hit (with 25 being the maximum) and the total number of attempts or shots fired.

SOF PAB
COGNITIVE PERFORMANCE

Note: Assessments of cognitive performance were accomplished using a set of measures developed to assess the impact of thermal and physical operational stressors on cognitive performance.[14] The cognitive abilities measured by the tasks in the present study were: memory, reaction time, vigilance, calculations, logical reasoning, and learning. The measures were implemented in a standardized fashion on color display computers used to present stimuli and record responses. Measurement times required about 20-30 minutes for each individual to complete the cognitive performance tasks.

The 6 cognitive tasks administered to the subjects in this study are described below in the order in which they were presented on the computer during each session.

1. Matching-to-Sample

The Matching-to-Sample task is designed to assess an individual's ability to quickly and accurately identify a comparison stimulus that is identical to a standard stimulus presented previously. The test is concerned with short-term spatial memory and pattern recognition skills. At the start of each trial the diver is presented with an eight-by-eight matrix as the sample stimulus. The sample stimulus is followed by a delay interval of either one or fifteen seconds. After the delay interval, two matrices are presented on the screen, side by side. One matrix matches the original exactly, and the other matrix differs. The diver is prompted to select the matching matrix. Accuracy data are recorded separately for each trial for short and long delays. Reaction time for each response is recorded for each trial. The Matching-to-Sample task requires about five minutes to complete.

2. Complex Reaction Time

The Complex Reaction Time task is a four-choice reaction time test that evaluates the reaction time of a diver when multiple choices must be made as to the location of the reaction time response. The task is also designed to evaluate information processing related to encoding, categorization, and response selection. On each trial of the task a small red square appears in one of four boxes presented near the center of the computer screen. The layout of the boxes is the same as the layout of the four arrow keys on the keyboard. When the red square appears in one of the boxes on the screen, the diver is to press the corresponding arrow key as quickly as possible. The red square then moves to a different (or the same) box and the individual again presses the corresponding arrow key. The diver continues to follow the red square as rapidly as possible while being as accurate as possible. Reaction times of all responses are recorded. Incorrect (wrong box) responses and lapses (responses that do not occur with two and a half seconds of the red square presentation) are tabulated separately for each trial. The Complex Reaction Task usually requires about one minute to complete.

3. Visual Vigilance

The Visual Vigilance task is concerned with sustained visual attention and choice reaction time. The purpose of the task is to test a diver's ability to continue making decisions and respond rapidly to visual symbols over a time period. In the Visual Vigilance task an individual must continuously monitor the computer screen on which letters and number characters are briefly (a half second) presented. If the character presented is either the letter "A" or the number "3" the individual is to press the down arrow key before the character is removed from the screen. If the character is any letter or number other than "A" or "3," no response is to be made. The number of errors of omission and the number of errors of commission are recorded. Reaction times for each response are recorded. The Visual Vigilance task consists of one hundred character presentations. The task is usually completed in about six minutes.

4. Serial Addition - Subtraction

The purpose of the Serial Addition-Subtraction task is to measure the ability to perform simple mathematical calculations. On each trial of the Serial Addition-

Subtraction task, two single digits are presented on the computer screen, separated by either a plus or a minus sign. The diver is to add or subtract the two digits accordingly and then enter the last single digit of the answer. Accuracy, the type of problem, and reaction time are recorded for each trial.

5. Logical Reasoning

The purpose of the Logical Reasoning task is to measure a diver/subject's general reasoning ability. The task presents a series of statements about the sequential arrangement of two-letter characters presented on the computer screen. The individual must determine whether the statement about the order of the two letters and the actual letter pair presented correspond or not. On each trial a statement about the order of two letters is presented in the center of the computer screen. Each statement is followed by the two letters, AB or BA. The individual must decide whether each statement correctly describes the order of the two letters or not. Responses are recorded by pressing the T keyboard key for a correct (true) statement and the F keyboard key for in incorrect (false) statement. On each trial, response accuracy, the statement type, and reaction time are recorded.

6. Repeated Acquisition

The Repeated Acquisition task is designed to measure a diver/subject's ability to learn, decode, or acquire, a new sequence. Specifically, an individual must learn a sequence of twelve key presses that are implemented on the Up (U), Down (D), Left (L), and Right (R) arrow keys on the computer keyboard. At the beginning of the task, an outline of an empty rectangle is presented on the center of the computer screen. A sequence is selected at the start of the task from a list of different sequences. The individual must basically learn the selected sequence. Each correct response fills in a portion of a rectangle on the computer screen with a solid square, starting on the left of the rectangle and ending with the portion on the far right of the rectangle. Each incorrect response blanks the screen for a half second. When the screen displaying the rectangle returns, the individual will be at the same place in the sequence as before the incorrect response. The task ends after the individual completes the same sequence correctly fifteen times. Each time a new session is started, the correct sequence differs from the previous session. The number of errors (incorrect responses) as well as the time to respond, in seconds, is recorded for each trial.